Experimental aspects of the RHIC spin program

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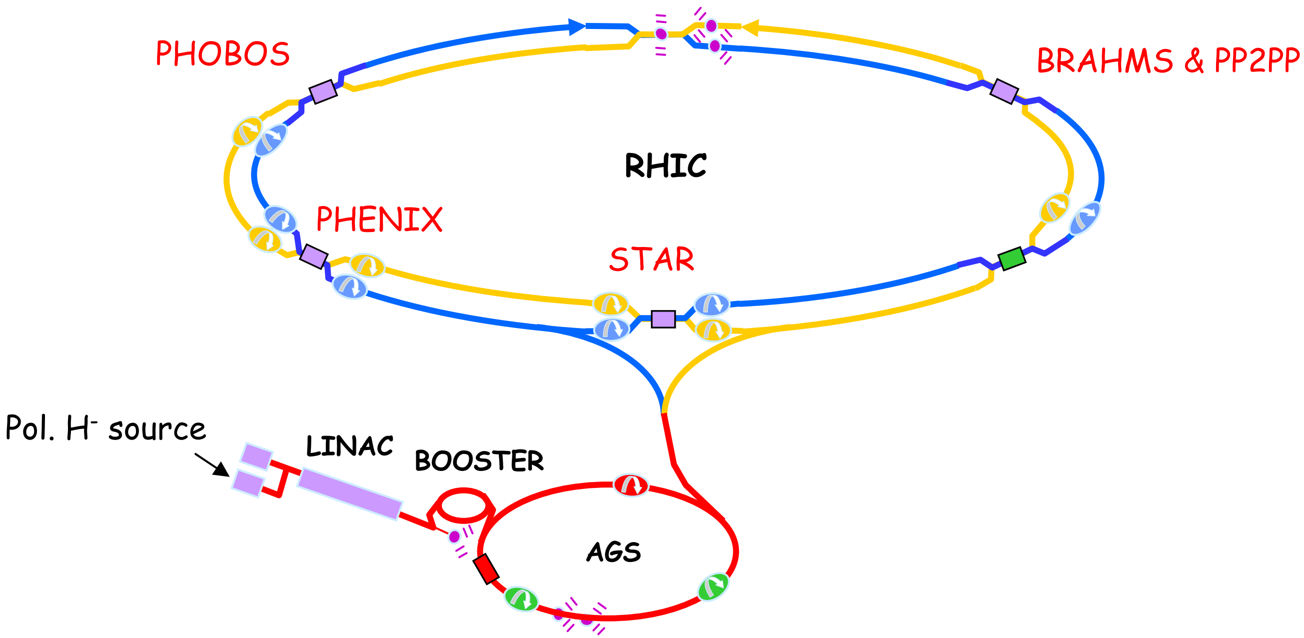
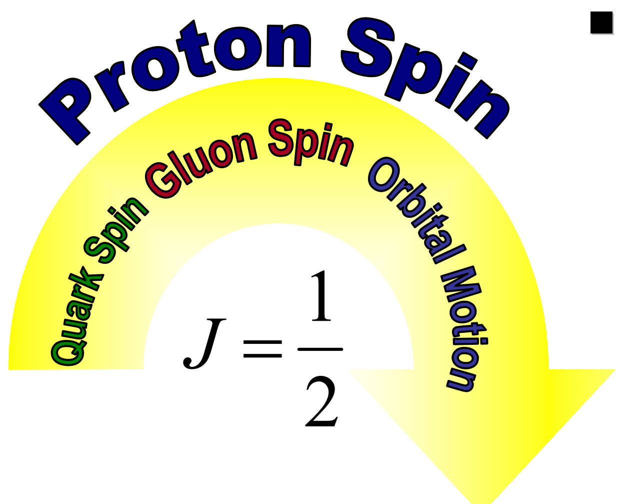
BNL

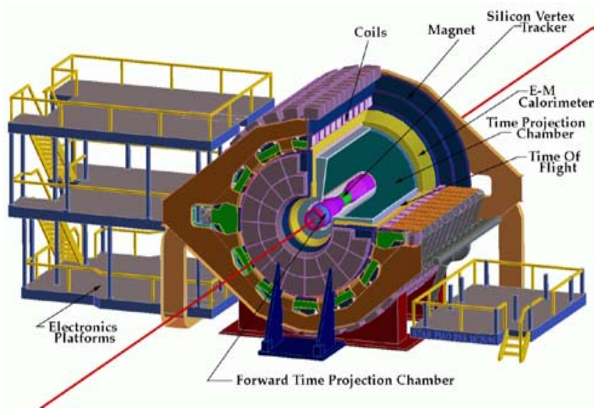


Outline

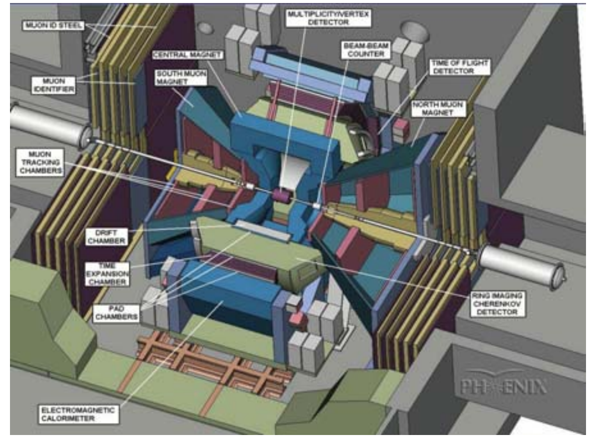


- Introduction

- Polarized proton collider RHIC



- The STAR detector

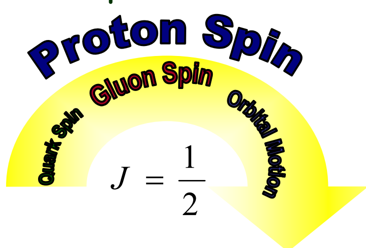


- The PHENIX detector
- First results (STAR / PHENIX)
- Future prospects (STAR / PHENIX)
- Summary and Outlook

Introduction

RHIC Spin program (e.g. ΔG)

- Fundamental question: How is the proton spin made up?



$$J = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$

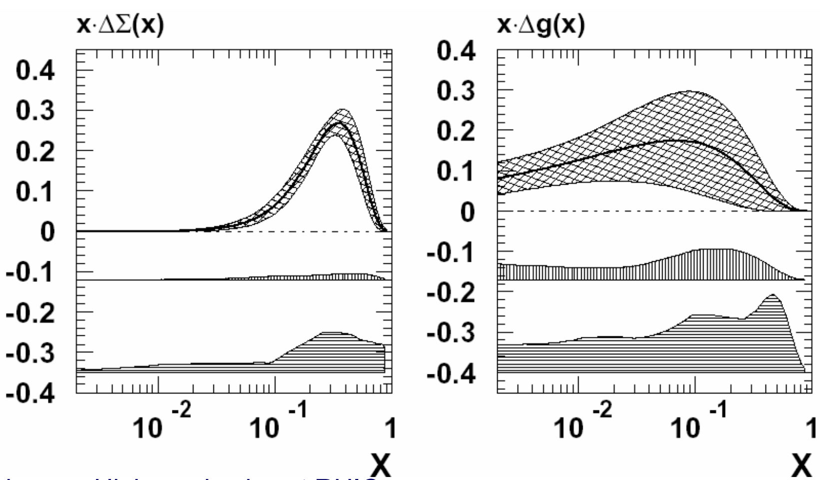
⇨ SMC result: Fraction of proton spin carried by quarks is small:

$$\Delta\Sigma_{(AB)} = 0.38^{+0.03}_{-0.03} \text{ at } Q_i^2 = 1\text{GeV}^2$$

⇨ Where is the spin of the proton then?

$$\Delta G \text{ and } (L_z^q + L_z^g)$$

⇨ SMC QCD-fit:



- At present: ΔG is only poorly constrained from scaling violations in fixed target DIS experiments

$$\Delta G_{(AB)} = 0.99^{+1.17}_{-0.31} \text{ at } Q_i^2 = 1\text{GeV}^2$$

B. Adeva et al., SMC Collaboration, Phys. Rev. D58 (1998) 112002.

- Need: New generation of experiments to explore the spin structure of the proton: polarized proton collisions at RHIC which allows to access directly ΔG in polarized pp collisions!

RHIC spin program:

- Unique multi-year program which has just started…!
- Explore various aspects of the spin structure and dynamics of the proton in a new domain:

⇨ Spin structure of the proton (gluon polarization, flavor decomposition, transversity)
⇨ Spin dependence of fundamental interactions
⇨ Spin dependence of fragmentation
⇨ Spin dependence in elastic polarized pp collisions

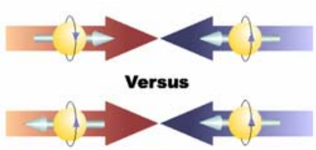
Introduction

Asymmetries

- Measurement of asymmetries (A): Principal approach to study spin effects
- Ultimately at RHIC, any combination of beam polarization (longitudinal (+/-) /transverse (↑/↓)) is possible, which allows to access different aspects of the proton spin structure

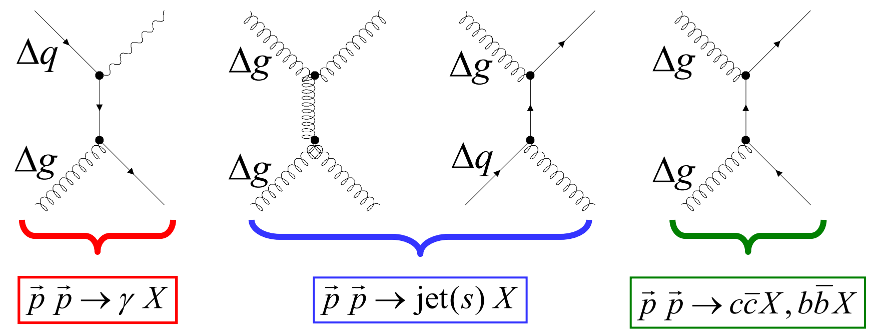
- Statistical significance (FOM=figure-of-merit):
  - Single spin asymmetry: $P^2 \cdot \int L dt$
  - Double spin asymmetry: $P^4 \cdot \int L dt$

- Double longitudinal-spin asymmetry:

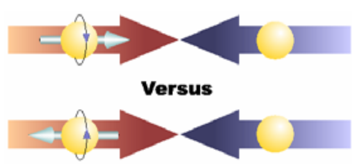


$$A_{LL} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})}$$

- Study helicity distribution functions, e.g. gluon polarization: ΔG!



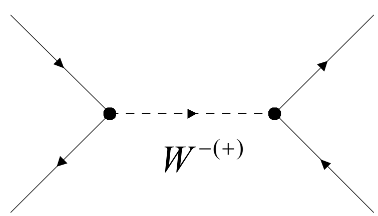
- Single longitudinal-spin asymmetry:



$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- Study parity violation effects and flavor decomposition!

$$\Delta d + \bar{u} \to W^-$$
$$\Delta \bar{u} + d \to W^-$$
$$\Delta \bar{d} + u \to W^+$$
$$\Delta u + \bar{d} \to W^+$$



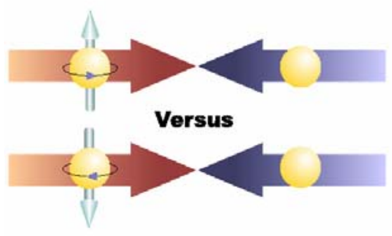
$$\boxed{W^{-(+)} \to l^- + \bar{\nu}_l \; (l^+ + \nu_l)}$$

$$l = e, \mu$$

Introduction

Asymmetries

- Single transverse-spin asymmetry:



$$A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$$

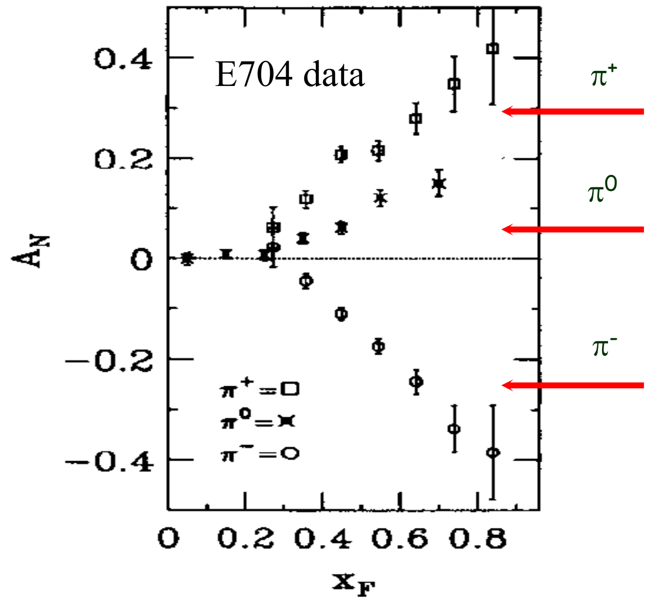
⇨ Study transverse spin effects:

- Sivers: include intrinsic transverse component, $k_\perp$, in initial state (orbital momentum)
- Collins: include intrinsic transverse component, $k_\perp$, in final state (transversity)
- Qiu and Sterman (Initial-state twist-3)/Koike (final-state twist-3)

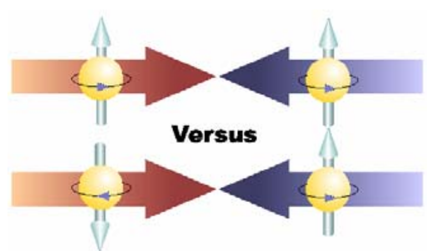
⇨ Basic, "naive QCD calculations" (leading-twist, ignore masses of quarks) predict: A_N=0 ($A_N \sim m_q/\sqrt{s}$)

⇨ Non-zero values of A_N have been observed at the FNAL experiment E704 for: $\vec{p} + p \rightarrow \pi^0 + X$

$\sqrt{s}$ = 20 GeV (10 X smaller than at RHIC), 0.5 < p_T < 2.0 GeV



- Double transverse-spin asymmetry:



$$A_{TT} = \frac{(\sigma_{\uparrow\uparrow} - \sigma_{\downarrow\downarrow}) - (\sigma_{\uparrow\downarrow} + \sigma_{\downarrow\uparrow})}{(\sigma_{\uparrow\uparrow} + \sigma_{\downarrow\downarrow}) + (\sigma_{\uparrow\downarrow} + \sigma_{\downarrow\uparrow})}$$

⇨ Study transverse dependent distribution functions e.g. in jet production or Drell-Yan production (Transversity $\delta q \Rightarrow$ Last unmeasured leading twist distribution function)!

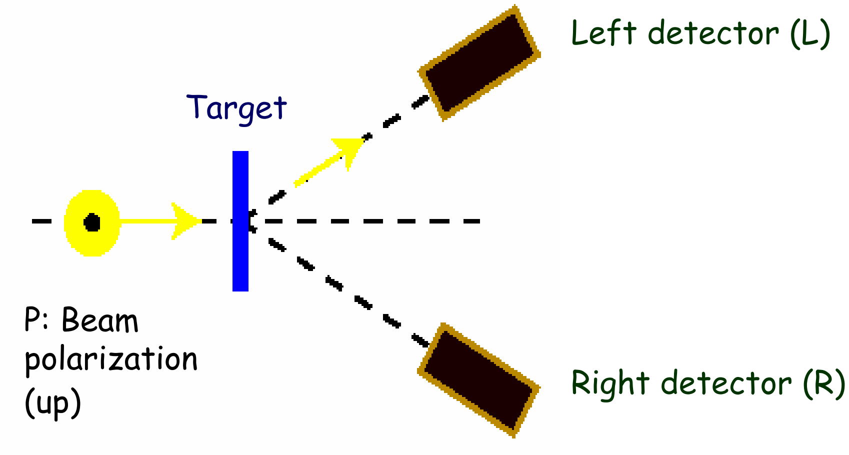
Introduction

Experimental aspects on asymmetry measurements at RHIC: A_N

- Measurement of A_N for forward π^0 production at STAR:

$$\vec{\mathrm{p}} + \mathrm{p} \rightarrow \pi^0 + \mathrm{X}$$ Forward π^0 ($\pi^0 \rightarrow \gamma\gamma$) production

x_F ($\approx E_{\pi^0}/E_{beam}$) ~ 0.2 - 0.6 and p_T ~ 1 - 3 GeV



- Asymmetry:

$$N_{\uparrow(\downarrow)}(\phi) = L_{\uparrow(\downarrow)}\sigma\Delta\Omega\left(1 \pm PA_N \cos\varphi\right)$$

$$N_\uparrow^L = L_{\uparrow(\downarrow)}\sigma\,\Delta\Omega\left(1 + PA_N\right) \qquad N_\downarrow^L = L_{\uparrow(\downarrow)}\sigma\,\Delta\Omega\left(1 - PA_N\right)$$

$$N_\uparrow^R = L_{\uparrow(\downarrow)}\sigma\,\Delta\Omega\left(1 - PA_N\right) \qquad N_\downarrow^R = L_{\uparrow(\downarrow)}\sigma\,\Delta\Omega\left(1 + PA_N\right)$$

$$\varepsilon = PA_N = \frac{\sqrt{N_L^\uparrow N_R^\downarrow} - \sqrt{N_L^\downarrow N_R^\uparrow}}{\sqrt{N_L^\uparrow N_R^\downarrow} + \sqrt{N_L^\downarrow N_R^\uparrow}}$$

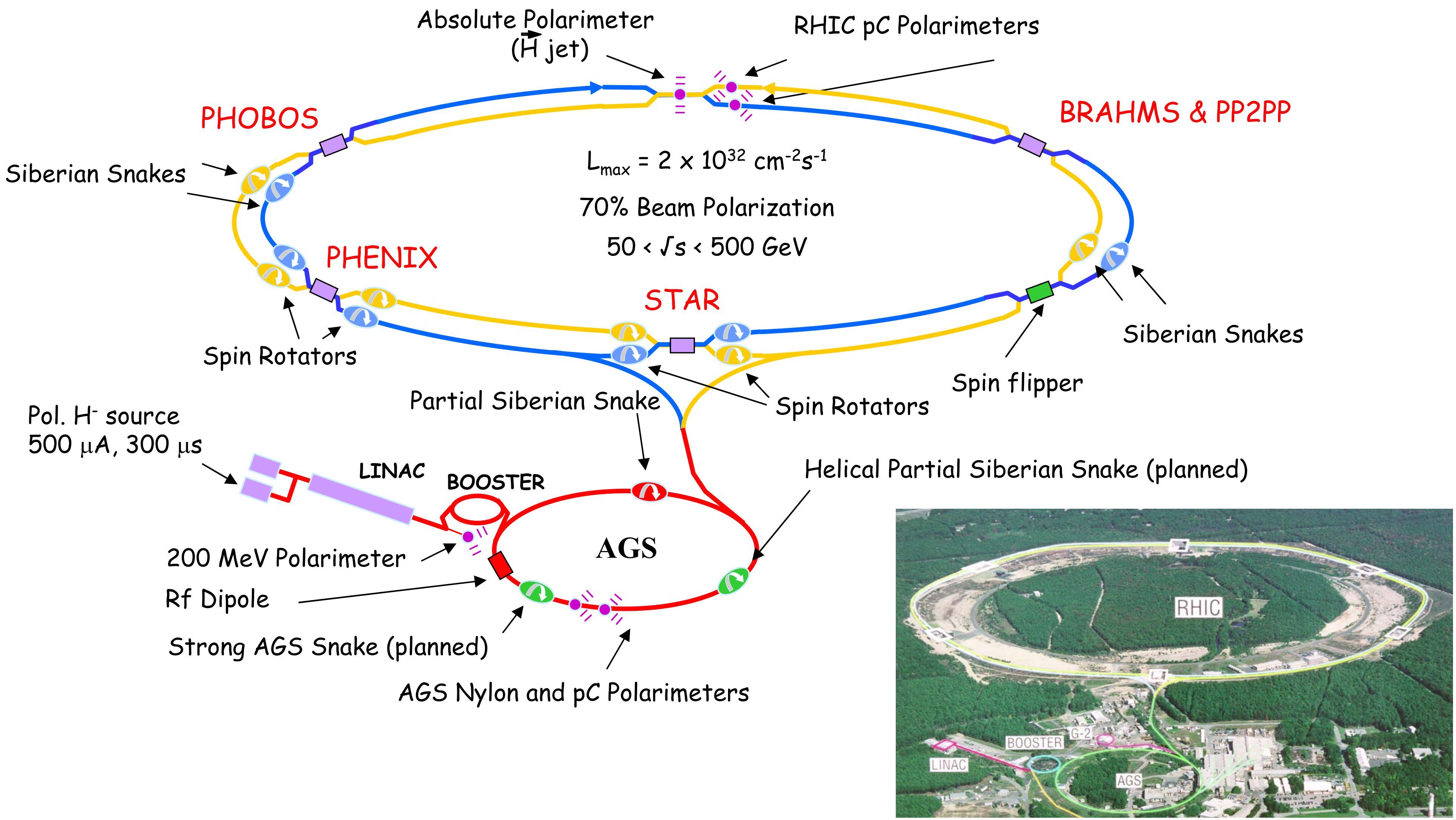
$$\varepsilon = PA_N = \frac{N_\uparrow/L_\uparrow - N_\downarrow/L_\downarrow}{N_\uparrow/L_\uparrow + N_\downarrow/L_\downarrow} = \frac{N_\uparrow - R\cdot N_\downarrow}{N_\uparrow + R\cdot N_\downarrow}$$

- Determination of A_N requires three measurements:
  1. Spin dependent event yield: $N_{\uparrow(\downarrow)}$
  2. Relative luminosity: $R=L_\uparrow/L_\downarrow$ (Essential for longitudinal asymmetry measurements!)
  3. Beam polarization: P

- A_N : DIFFERENCE over SUM – In general quite small ⇨ Require therefore:
  1. Statistical precision
  2. Control of systematic effects

Polarized proton collider RHIC

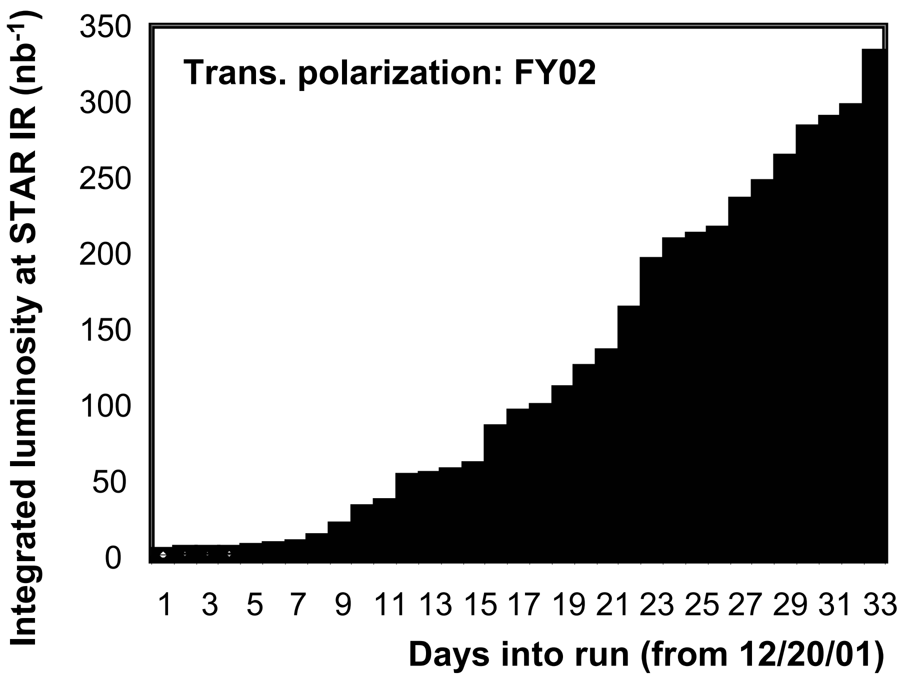
- ## Overview of RHIC polarized pp collider complex

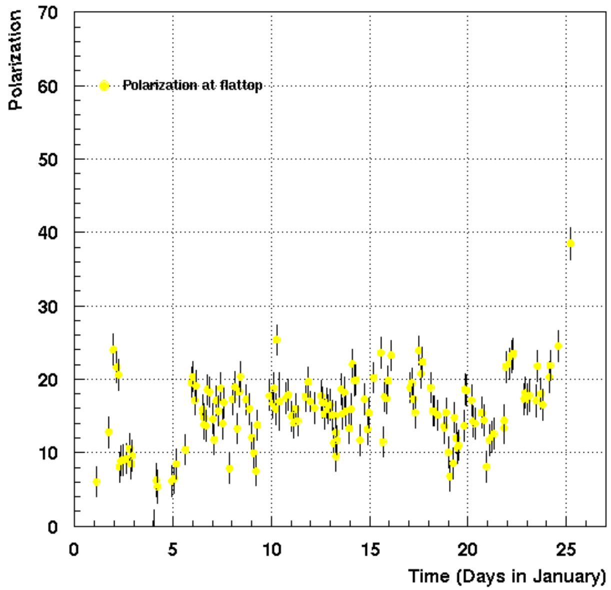


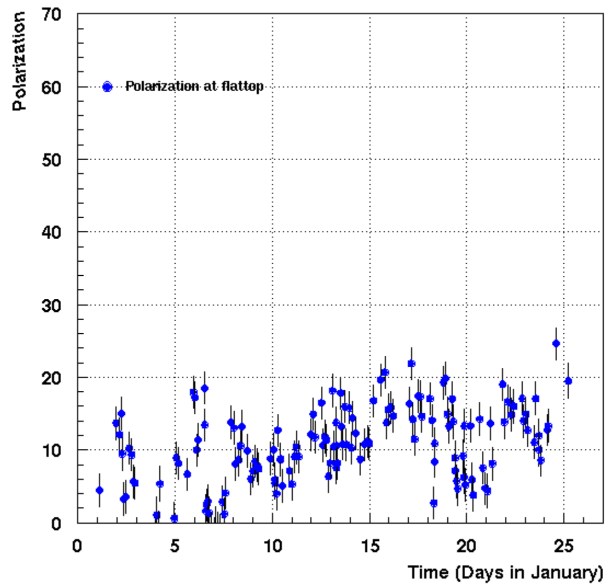
Polarized proton collider RHIC

Machine performance overview (FY02)

- Achievements in FY02:
  - ⇨ Beam energy: 100 GeV
  - ⇨ Inst. luminosity: ~ 5 • 10^{29} s^{-1} cm^{-2}
  - ⇨ Integrated luminosity: ~ 0.3pb^{-1}
  - ⇨ Bunch crossing time: 213ns
  - ⇨ Polarization: ~ 0.2 (transverse)
  - ⇨ First transverse spin result (A_N)!





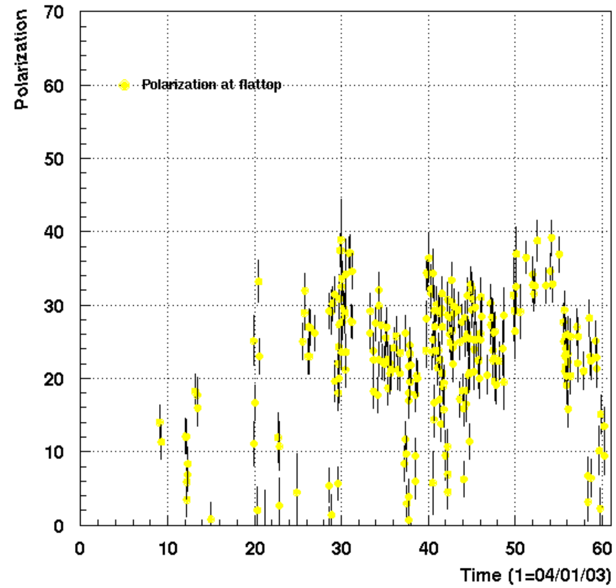


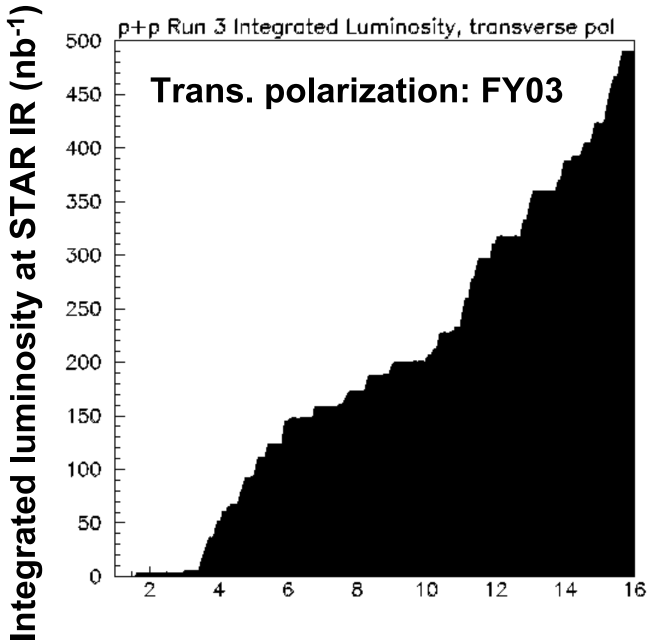
Blue and Yellow Beam polarization (RHIC CNI) FY02

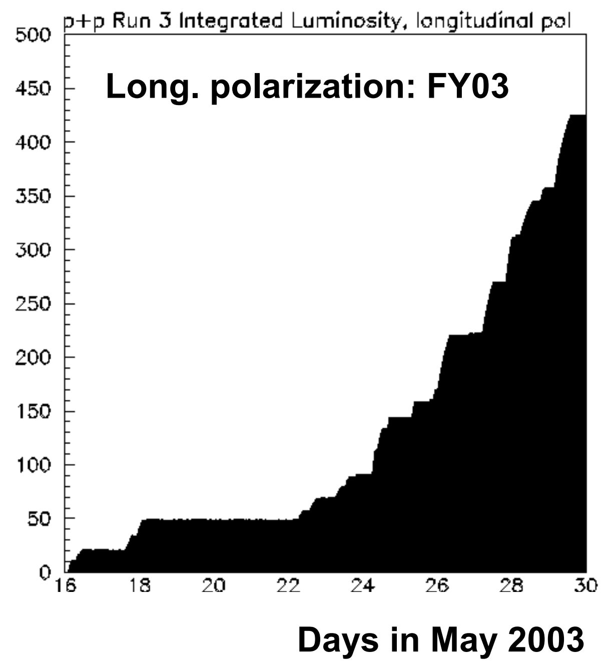
Polarized proton collider RHIC

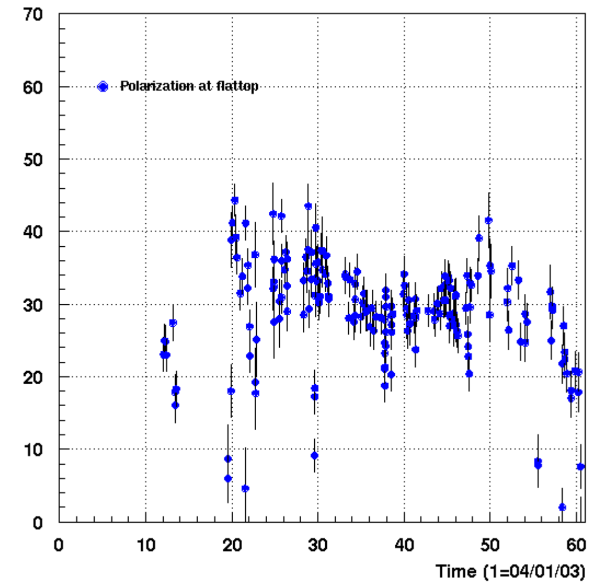
Machine performance overview (FY03)

- Achievements in FY03:
  - ⇨ Beam energy: 100 GeV
  - ⇨ Inst. luminosity: ~ $2 \cdot 10^{30}\ s^{-1}\ cm^{-2}$
  - ⇨ Integrated luminosity: ~ 0.5 pb^{-1} (transverse) ~ 0.4 pb^{-1} (longitudinal)
  - ⇨ Bunch crossing time: 213ns
  - ⇨ Polarization: ~ 0.3 (transverse and longitudinal)
  - ⇨ First longitudinal spin result (A_{LL})!



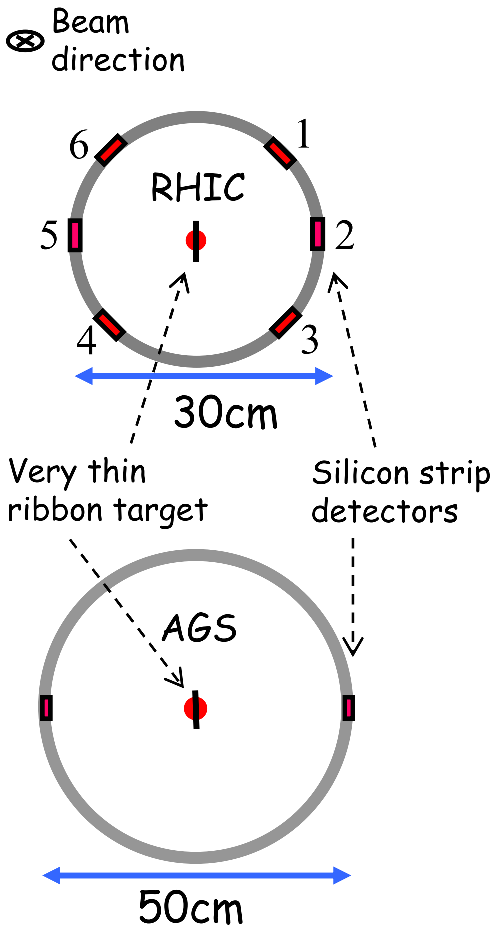


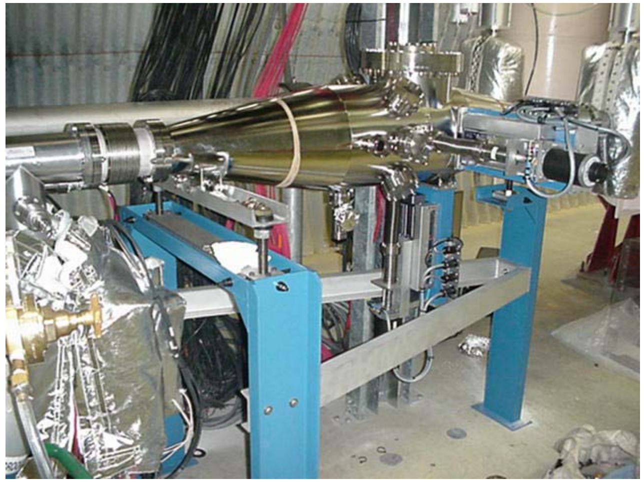




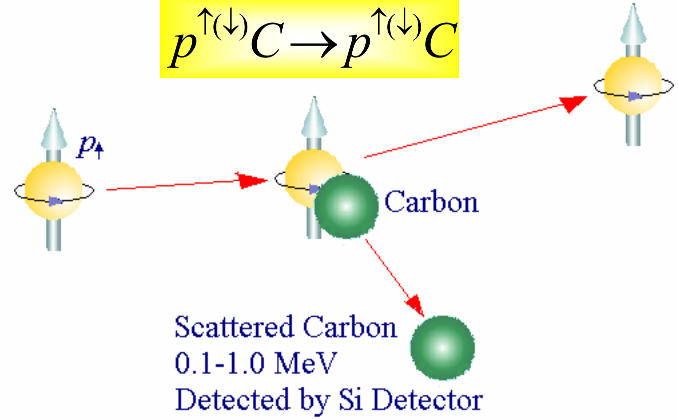
Blue and Yellow Beam polarization (RHIC CNI) FY03

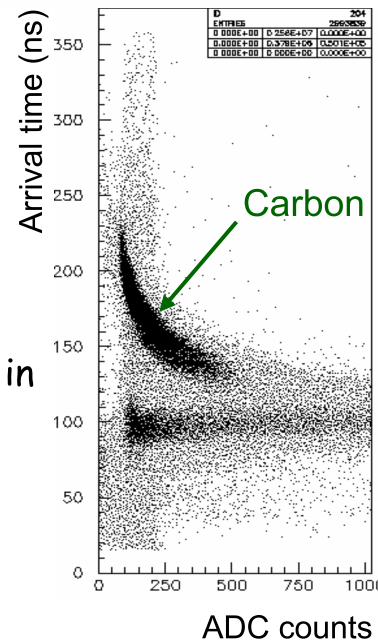
RHIC/AGS CNI polarimeters





$$p^{\uparrow(\downarrow)}C \rightarrow p^{\uparrow(\downarrow)}C$$





pC CNI elastic scattering (-t=0.008-0.025GeV/c²):
⇨ Detect recoil carbon

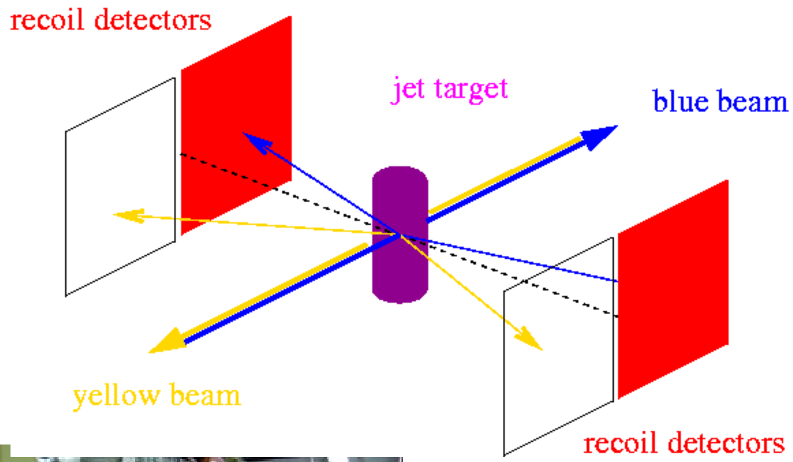
- Very thin carbon ribbon target (5μg/cm² × 25 mm) in the RHIC beam
- Measure scattered recoil carbon at θ_{Lab}~ 90° with E_{carbon}= 0.1 - 1 MeV (silicon strip detectors)
- Measure E and TOF to identify recoil carbon ions, determine 4-momentum (-t) and determine left-right/up-down asymmetries
- Readout system based on wave-form digitizer (WFD) board to allow high counting rates (~0.5 MHz)

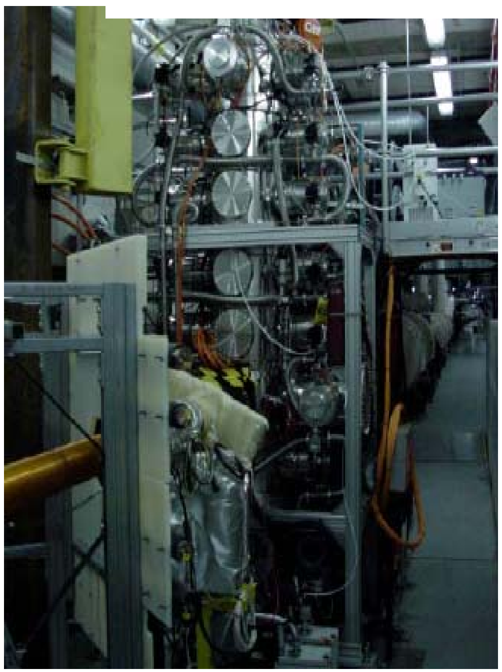
$$\varepsilon = PA_N = \frac{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} - \sqrt{N_L^{\downarrow}N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow}N_R^{\downarrow}} + \sqrt{N_L^{\downarrow}N_R^{\uparrow}}}$$

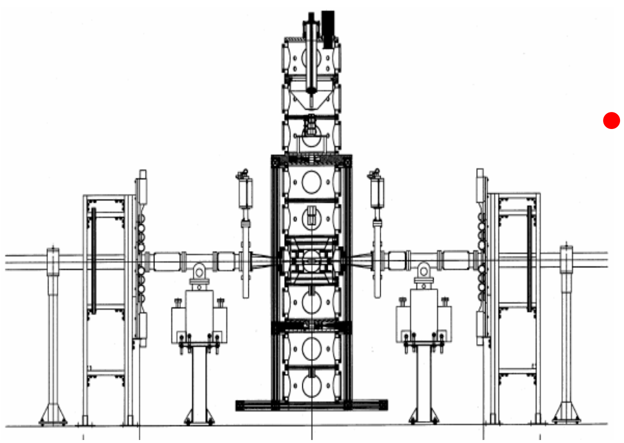
$$P_{beam} = \frac{\varepsilon}{A_N}$$

Polarized proton collider RHIC

- RHIC polarized gas-jet target







- Absolute polarization measurement using an internal polarized hydrogen gas jet target (⇨ 10% normalization uncertainty on ΔG requires knowledge of beam polarization to ±5%): Calibrate fast RHIC CNI polarimeter!
- Polarimeter process: Elastic pp scattering at very low t in the CNI region ($0.001<|t|<0.02 GeV/c^2$)
- Measure recoil proton in elastic pp scattering using silicon strip recoil detectors
- Properties of polarized hydrogen gas jet target:
  - Polarization: ~90%
  - Density: $5\cdot10^{11}$ p/cm^3
  - Target polarization measurement: Breit-Rabi polarimeter
- Transfer target polarization to beam polarization using self-calibration method: A_N for $p^{\uparrow}_{\text{target}}\, p \rightarrow pp$ $\quad pp^{\uparrow(\downarrow)}_{\text{beam}} \rightarrow pp$ are identical in magnitude:

$$P_{\text{target}} \rightarrow A_N^{pp} \rightarrow P_{\text{beam}}^{pp} \rightarrow A_N^{pC} \rightarrow P_{\text{beam}}^{pC}$$

- Goal: 10% accuracy on beam polarization in 2004 with final goal of 5% in 2005

Polarized proton collider RHIC

Overview of commissioning status

- Commissioning status:

☑ Siberian snake and spin rotator magnets successfully commissioned

☑ Fast polarimeters in AGS/RHIC demonstrated to work

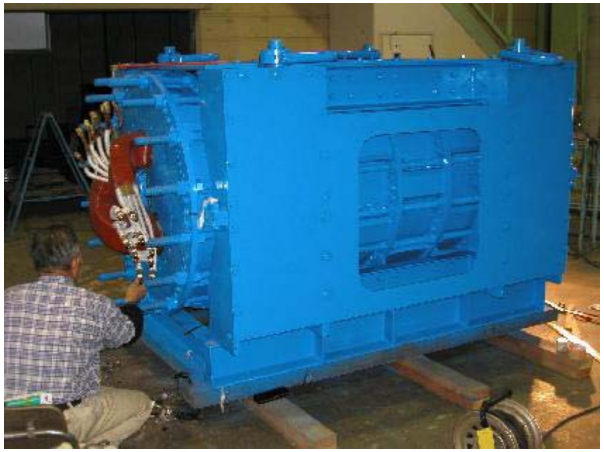
☑ Spin transfer AGS to RHIC demonstrated to work

☐ Installation and commissioning of AGS partial snake magnets

☐ Commissioning of polarized gas jet target (⇨ Absolute polarization measurement!)

☐ Commissioning of 250GeV ramp

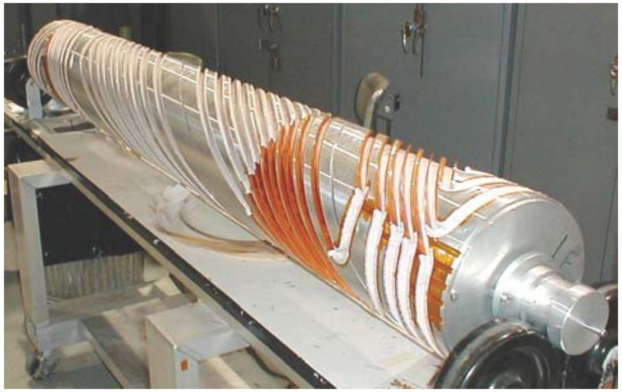
☐ **Adequate time for commissioning and luminosity development…!**



⇨ 5 % helical snake build at Tokana Industries funded by RIKEN (Just arrived at BNL!). Installation: Jan. 2004!

RHIC SPIN effort is in the beginning of its multi-year program!

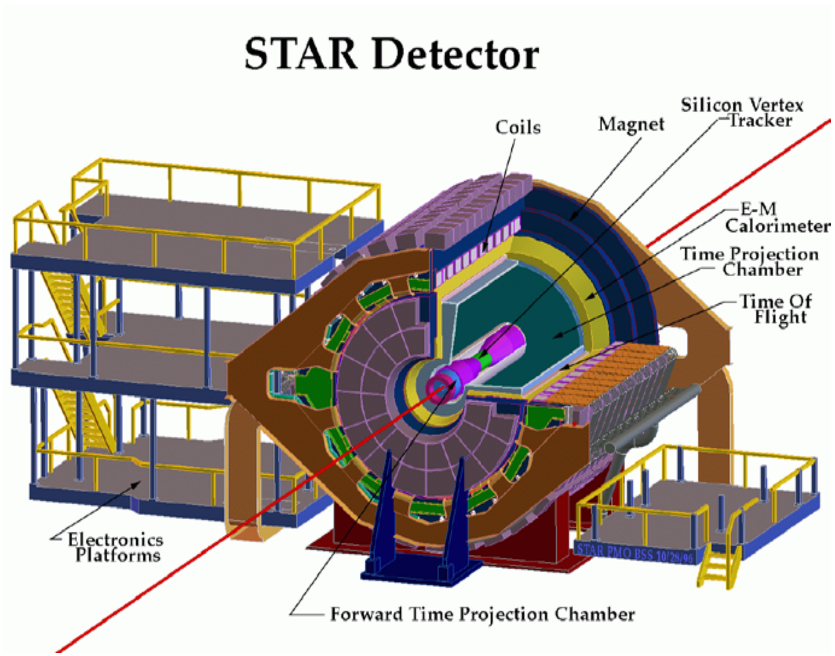
- Warm snake avoids polarization mismatch at AGS injection and extraction
- Cold strong snake eliminates all depolarizing resonances in AGS

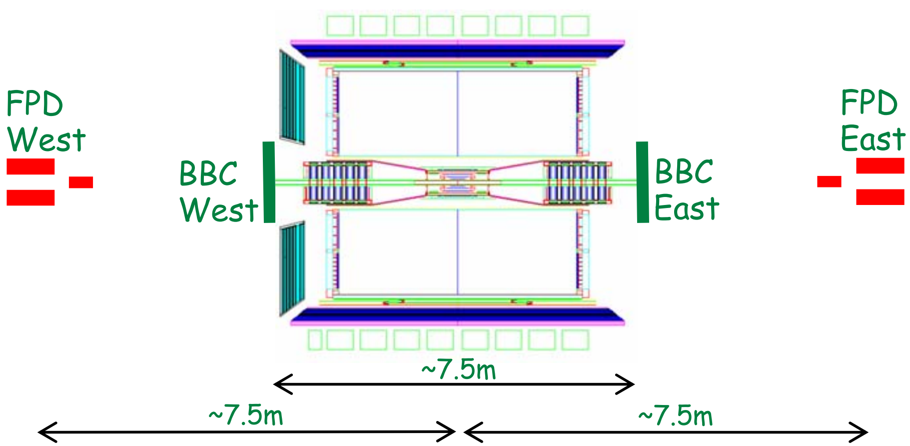


⇨ 30% s.c. helical snake build at SMD (AIP) Installation: Oct. 2004!

The STAR detector

Overview

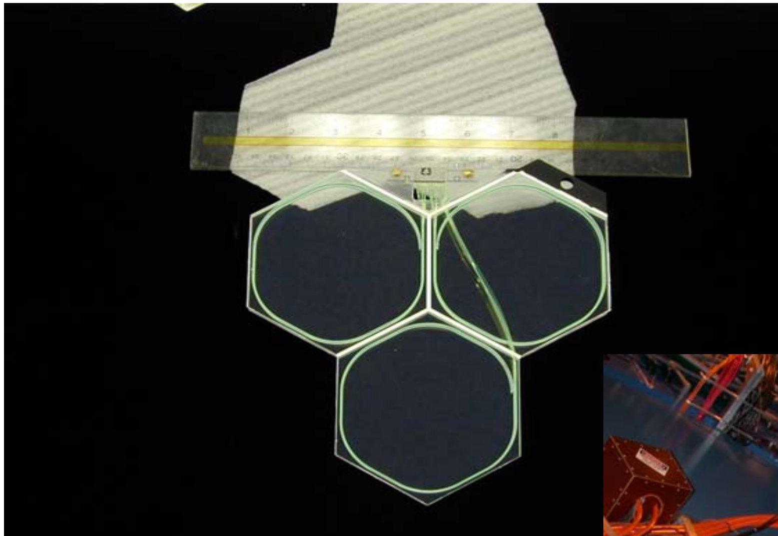




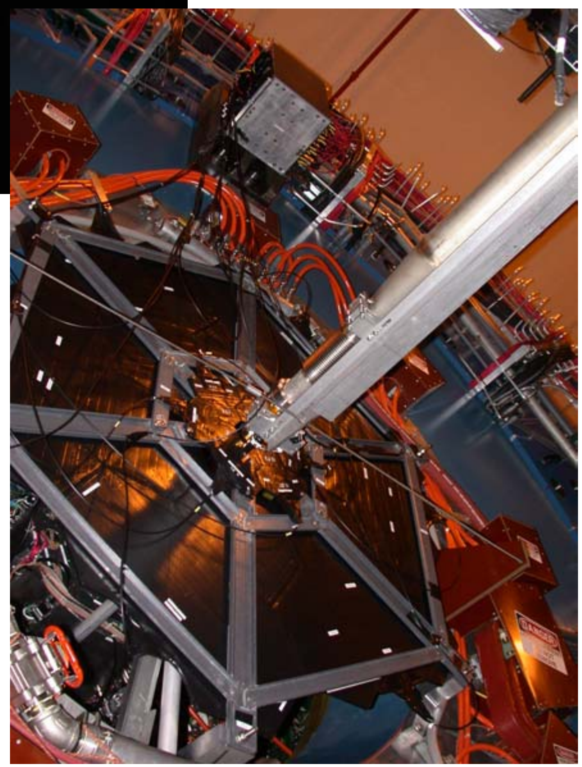
Upgrade program of the STAR experiment for the first polarized proton collisions (FY02/FY03):

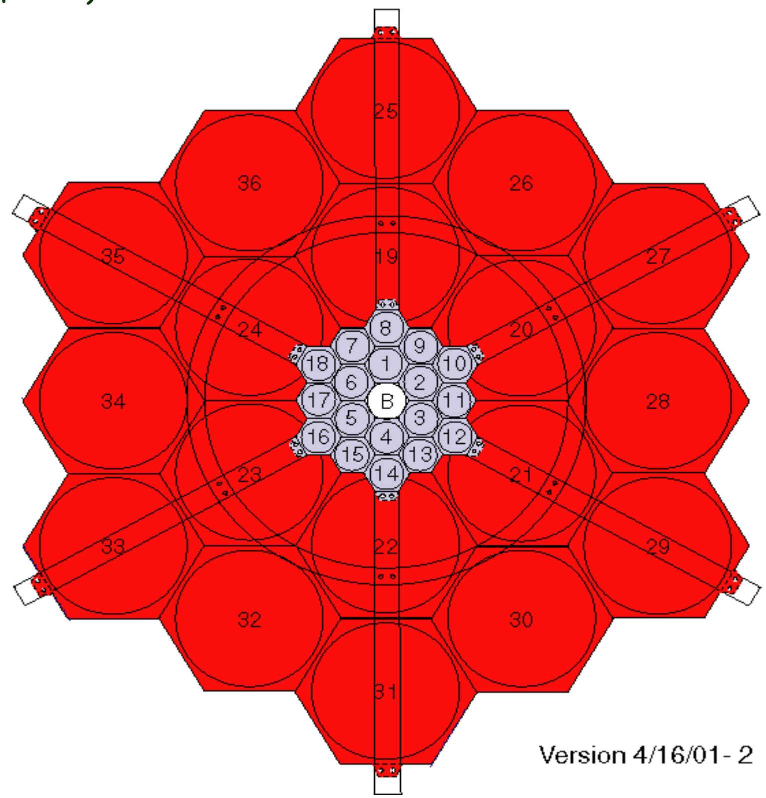
- Beam-Beam Counter (BBC): ($2 < \eta < 5$)
  - ⇨ Relative luminosity measurement
  - ⇨ Rejection of beam-gas event in pp collisions
  - ⇨ Minimum bias trigger
  - ⇨ Beam tuning to make collisions at STAR
  - ⇨ Luminosity monitor
- Forward-Pion Detector (FPD) ($3 < \eta < 4$)
  - ⇨ Electromagnetic calorimeter system: Prototype setup of 3 Pb-glass arrays and 1 Pb-scintillator calorimeter east side for FY02
  - ⇨ Upgrade in FY03: Pb-glass array on EAST/WEST
  - ⇨ Energy and shower profile measurement ($\pi^0 \to \gamma\gamma$)
  - ⇨ Event yield for Forward π^0 production
- Commissioning of EM-calorimeter modules and trigger (Barrel: $-1 < \eta < 1$ & Endcap: $1.09 < \eta < 2$)
- Commissioning of spin scaler system

STAR Beam-Beam Counter (BBC)



- Hexagonal scintillator array structure at ±3.5m from IP:
  - ⇨ Inner annulus: inner (outer) diameter 9.6cm (48cm) of 18 pixels ($3.3 < \eta < 5.0$)
  - ⇨ Outer annulus: inner (outer) diameter 38cm (193cm) of 18 pixels ($2.0 < \eta < 3.3$)

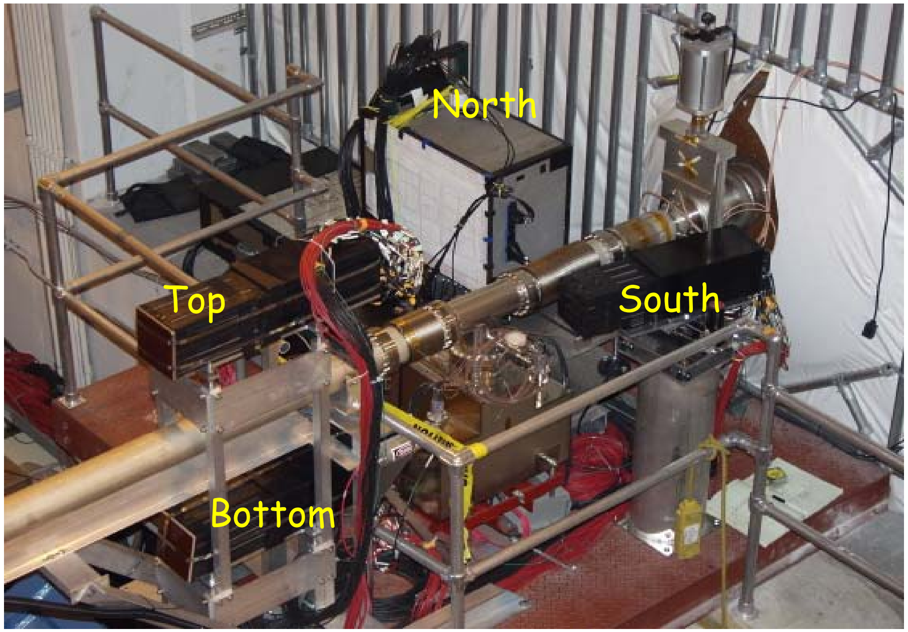




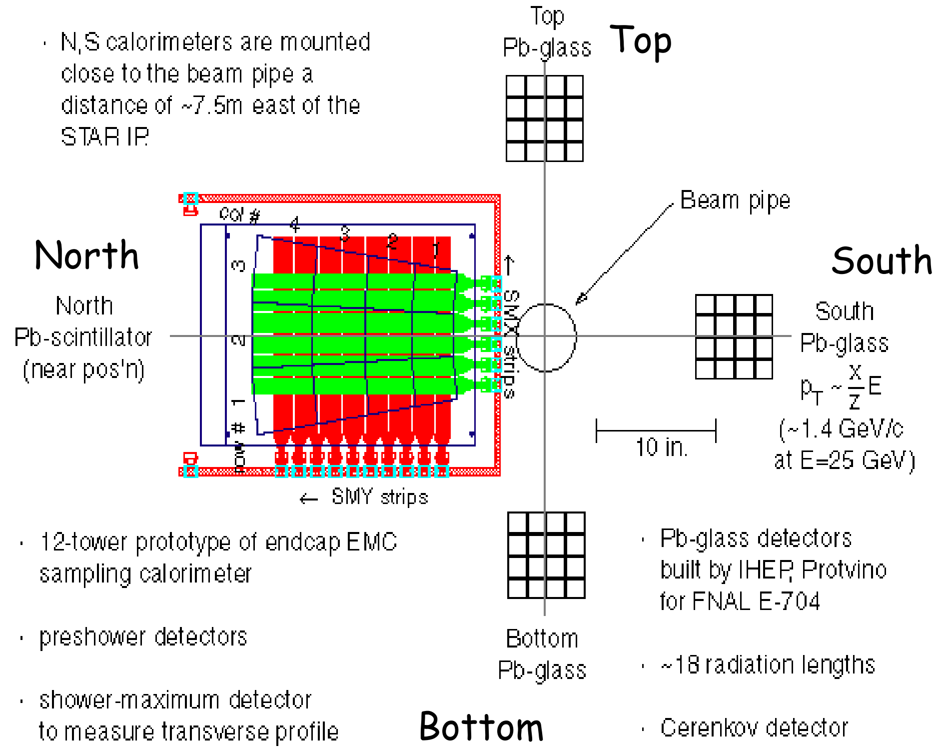
- Singe scintillator tile:
  - ⇨ 1 cm thick scintillator
  - ⇨ 4 optical fibres for light collection
  - ⇨ ~ 15 photoelectron/MIP

The STAR detector

- Forward-Pion Detector (FPD) prototype setup (FY02)



- N,S calorimeters are mounted close to the beam pipe a distance of ~7.5m east of the STAR IP.

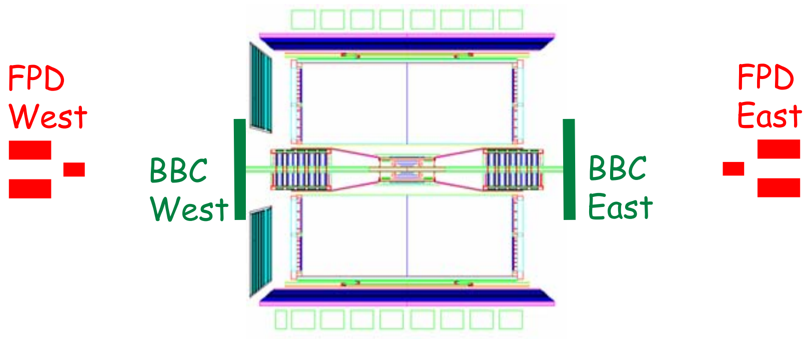


- 12-tower prototype of endcap EMC sampling calorimeter
- preshower detectors
- shower-maximum detector to measure transverse profile
- extensively tested at SLAC

- Pb-glass detectors built by IHEP, Protvino for FNAL E-704
- ~18 radiation lengths
- Cerenkov detector

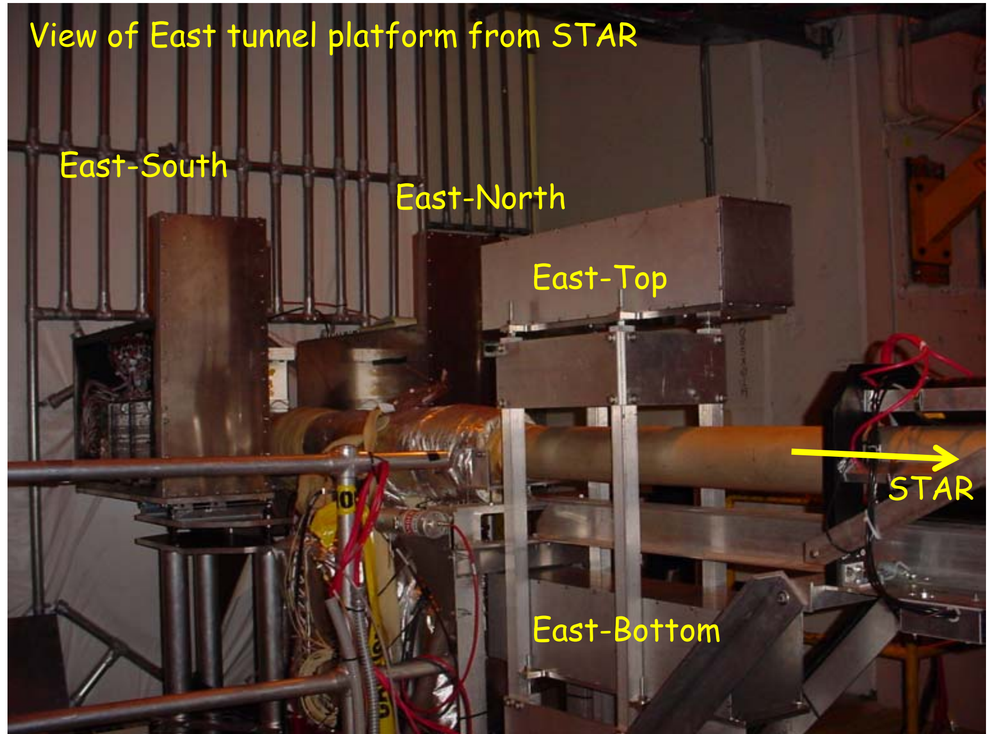
The STAR detector

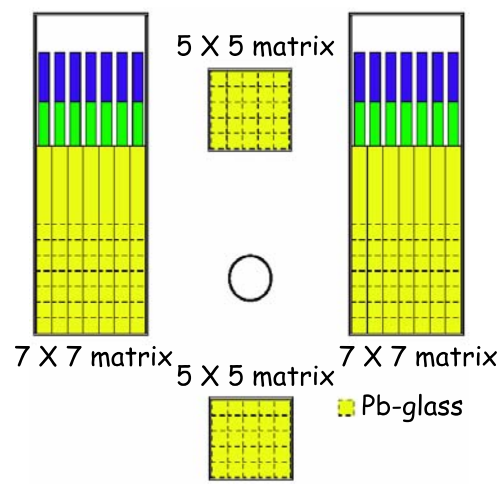
- FPD upgrade for FY03 run



- Physics motivation:
  - A_N measurement for $\vec{p} + p \to \pi^0 + X$
  - Tuning of STAR spin rotator (Local polarimeter)
  - Gluon density in heavy nuclei: $d + Au \to \pi^0 + X$

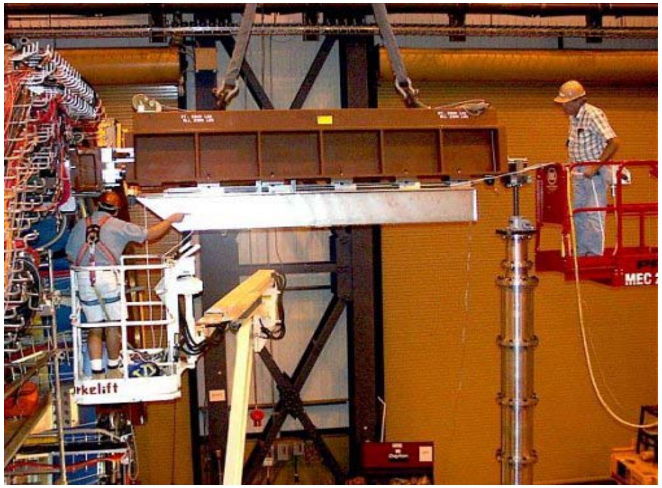
- Acceptance:
  - Forward rapidity: $3 < \eta < 4$
  - High x_F: $x_F > 0.2$
  - Moderate p_T: $1 < p_T < 4$ GeV

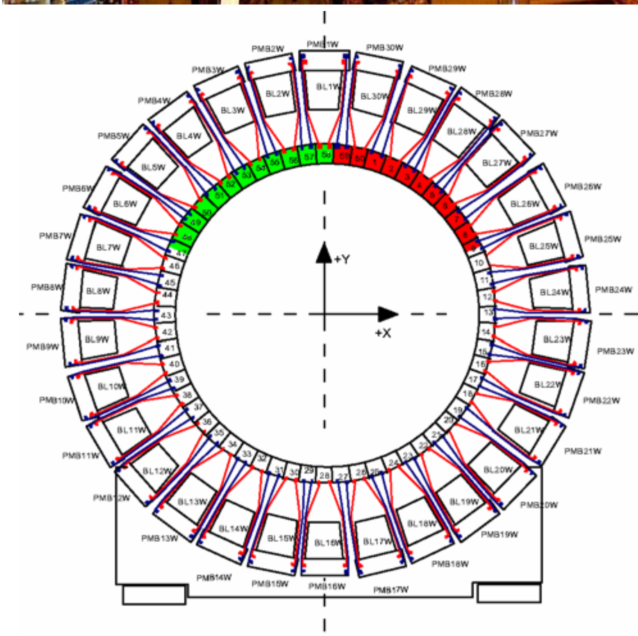


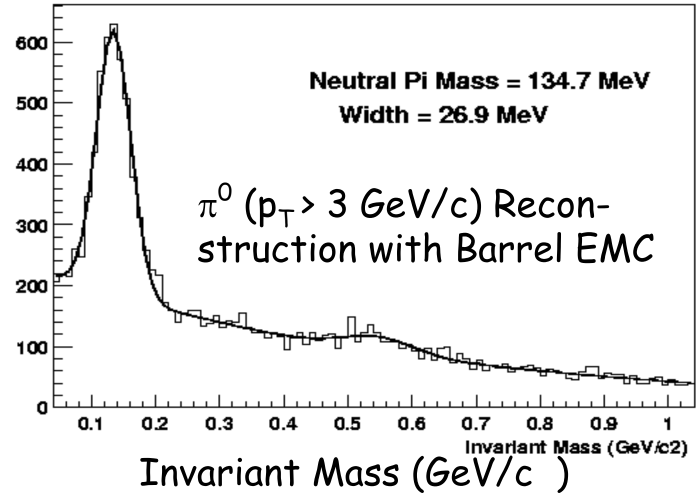


The STAR detector

■ STAR calorimeter system: Barrel



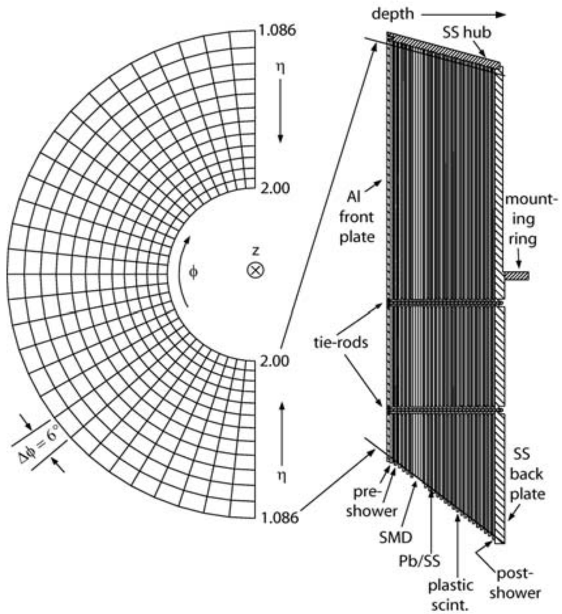


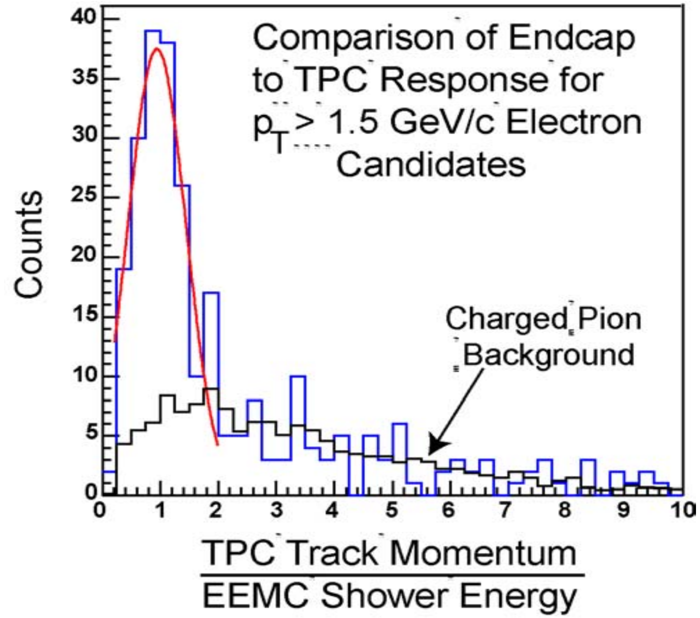


- Barrel Calorimeter: $-1 < \eta < 1$
  - ⇨ Lead-scintillator EM calorimeter (~20 X_0)
  - ⇨ 120 modules with: $\Delta\Phi \times \Delta\eta = 0.1 \times 1.0$
  - ⇨ 40 towers per module: $\Delta\Phi \times \Delta\eta = 0.05 \times 0.05$
  - ⇨ Shower max. detector (SMD): wire proportional counter (γ/π^0 discrimination)
  - ⇨ Pre-shower layers
  - ⇨ Installed (FY04): 90/120
  - ⇨ Instrumented towers: 75/120
  - ⇨ Instrumented SMD: 75/120

The STAR detector

- STAR calorimeter system: Endcap

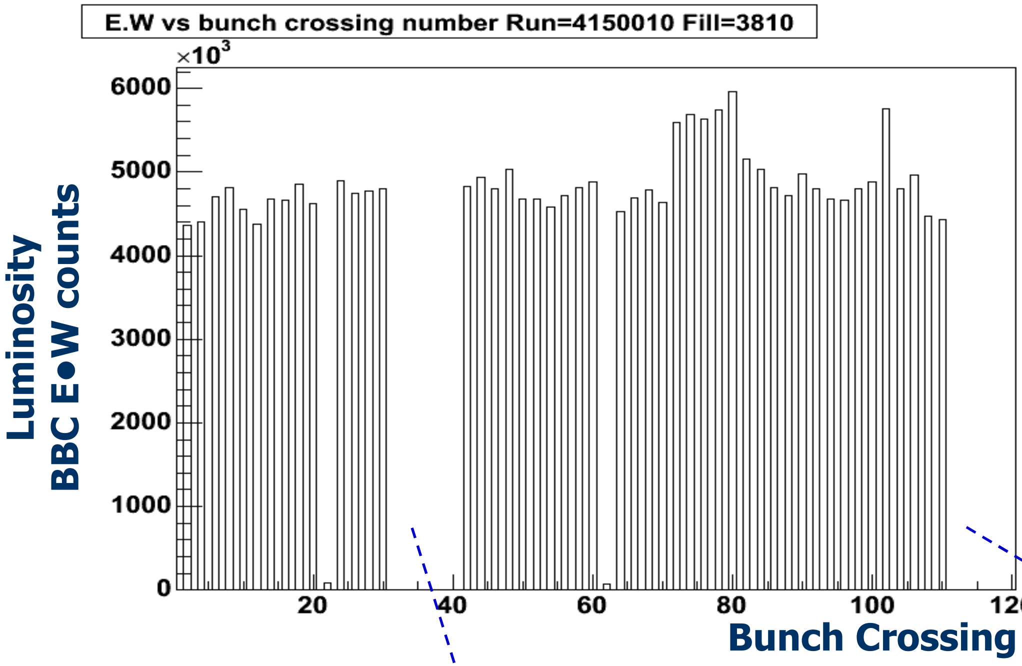


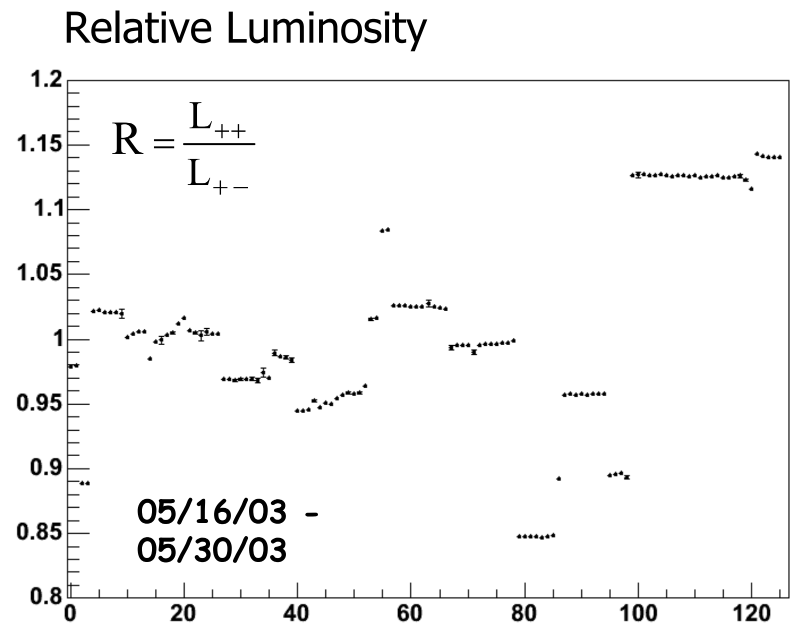


- Endcap calorimeter: $1.09 < \eta < 2$
  - ⇨ Lead-scintillator calorimeter (~24 X_0)
  - ⇨ 780 towers with: $\Delta\Phi = 0.1$, $\Delta\eta = 0.057$ at η = 1.09 to 0.099 at $\eta = 2$
  - ⇨ Shower max. detector (SMD): scintillator strip layers (γ/π^0 discrimination)
  - ⇨ Pre-shower and post-shower layers
  - ⇨ Complete EEMC installed (FY04 run)
  - ⇨ Instrumented: 720 towers and 1/3 (4 sectors) SMD and pre/post shower

First results (STAR)

- STAR BBC luminosity monitoring

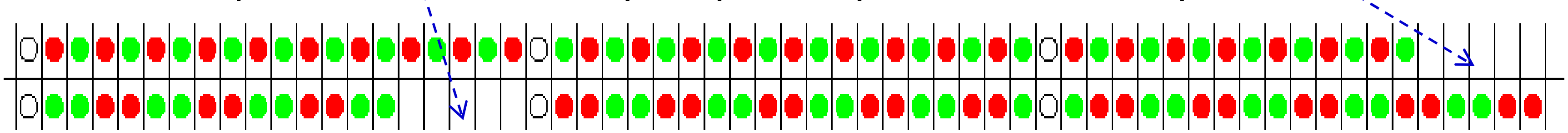




- Abort gaps ⇨ beam-gas background!

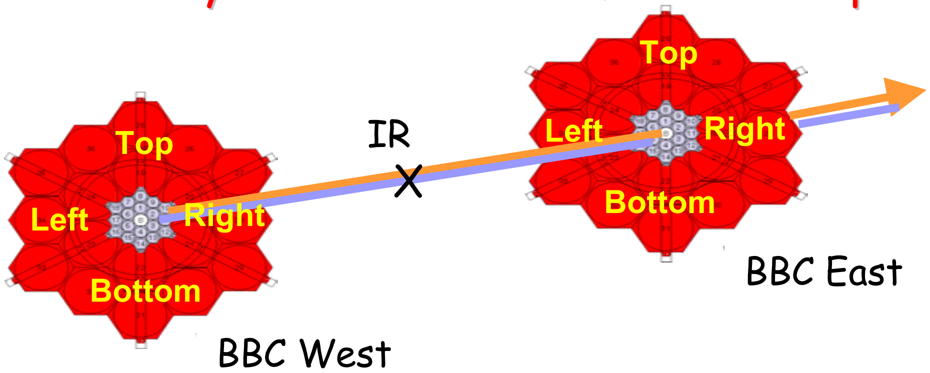
- Determine relative luminosity of bunch-crossings with different polarization
- Accuracy: δR_{stat} ~ 10^{-4} – 10^{-3} and δR_{sys} ~ $3 \cdot 10^{-3}$

Polarization pattern at STAR: Spin Up ● Spin Down ● Unpolarized ○

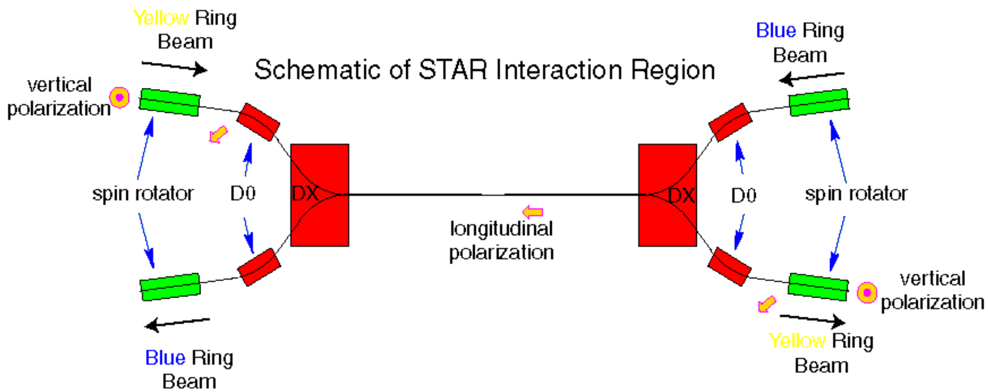


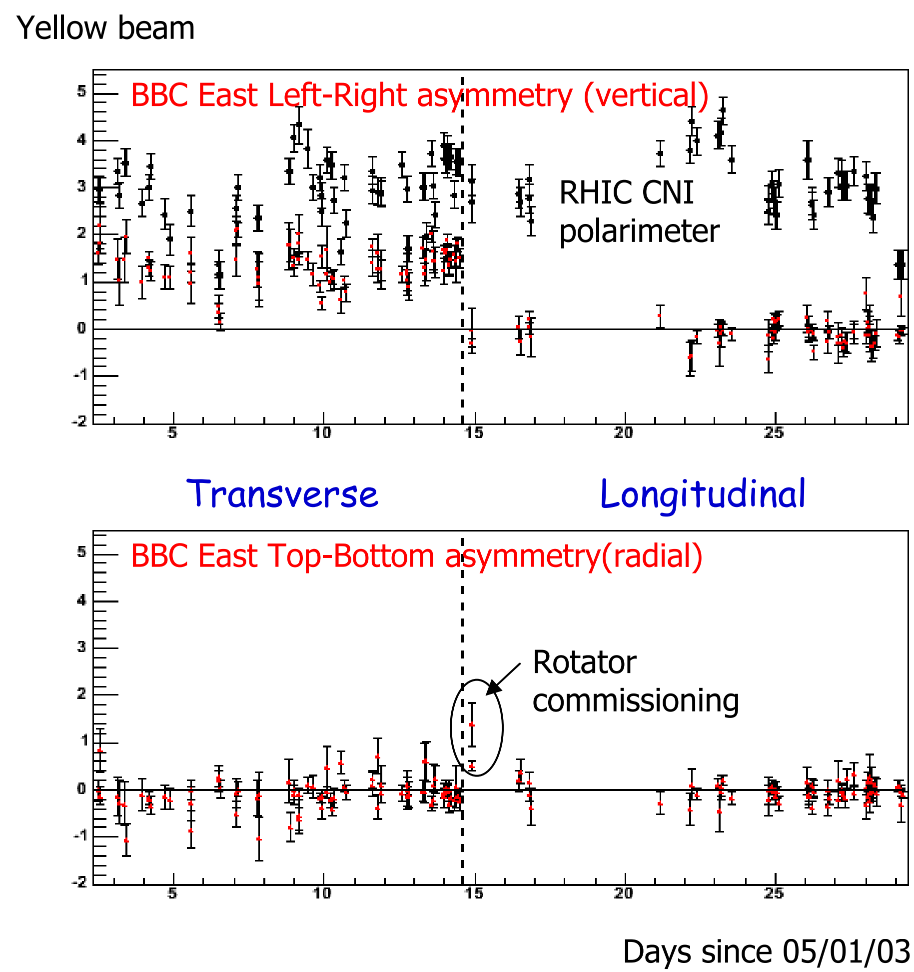
First results (STAR)

- BBC asymmetries: Used for STAR spin rotator tuning during FY03 run



$3.3<|\eta|<5.0$ (small tiles only)

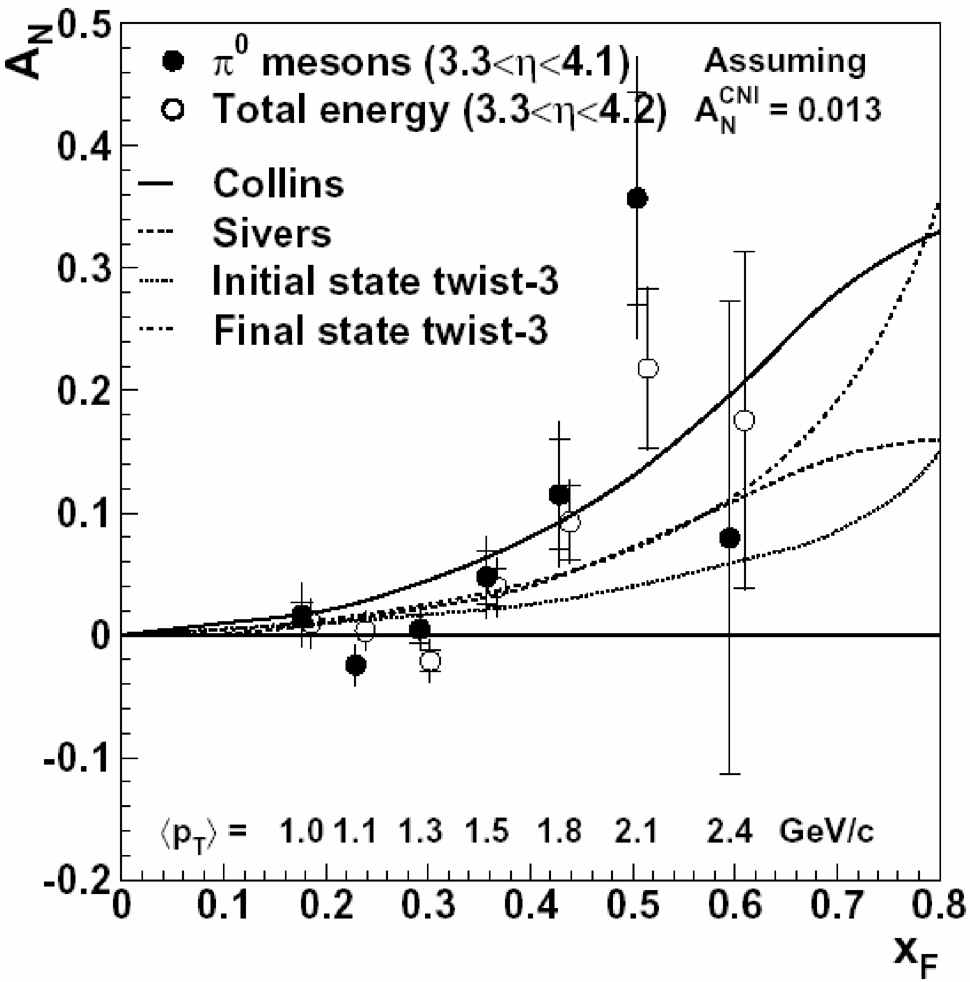




- Spin manipulation around IR's:
  1. Stable spin direction at RHIC is vertical
  2. Spin Rotater brings spin to almost radial orientation
  3. D0/DX magnet causes spin precession
  4. Longitudinal at IR
  5. DX/D0/Spin Rotater put spin back to vertical

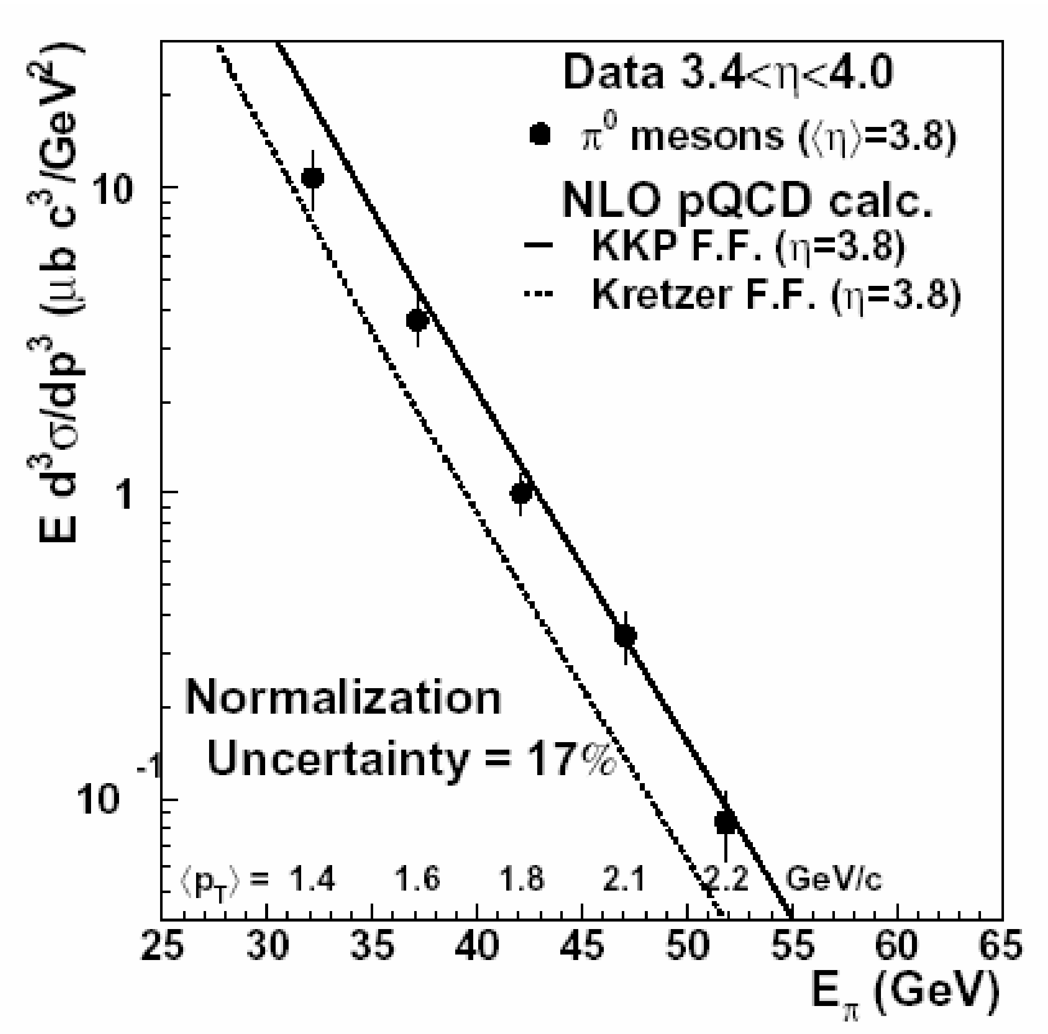
First results (STAR)

- First measurement of A_N for forward π^0 production at RHIC



- A_N is found to increase with energy similar to E704 result ($\sqrt{s}$ = 20 GeV (10 X smaller than at RHIC), 0.5 < p_T < 2.0 GeV)
- This behavior is also seen by several models which predict non-zero A_N values
- Several approaches beyond the basic "naive QCD calculations" yield non-zero A_N values at RHIC energies:
  - ⇨ Sivers: include intrinsic transverse component, $k_\perp$, in initial state (orbital momentum) (before scattering takes place)
  - ⇨ Collins: include intrinsic transverse component, $k_\perp$, in final state (transversity) (after scattering took place)
  - ⇨ Qiu and Sterman (Initial-state twist-3)/Koike (final-state twist-3): more "complicated QCD calculations" (higher-twist, multi-parton correlations)

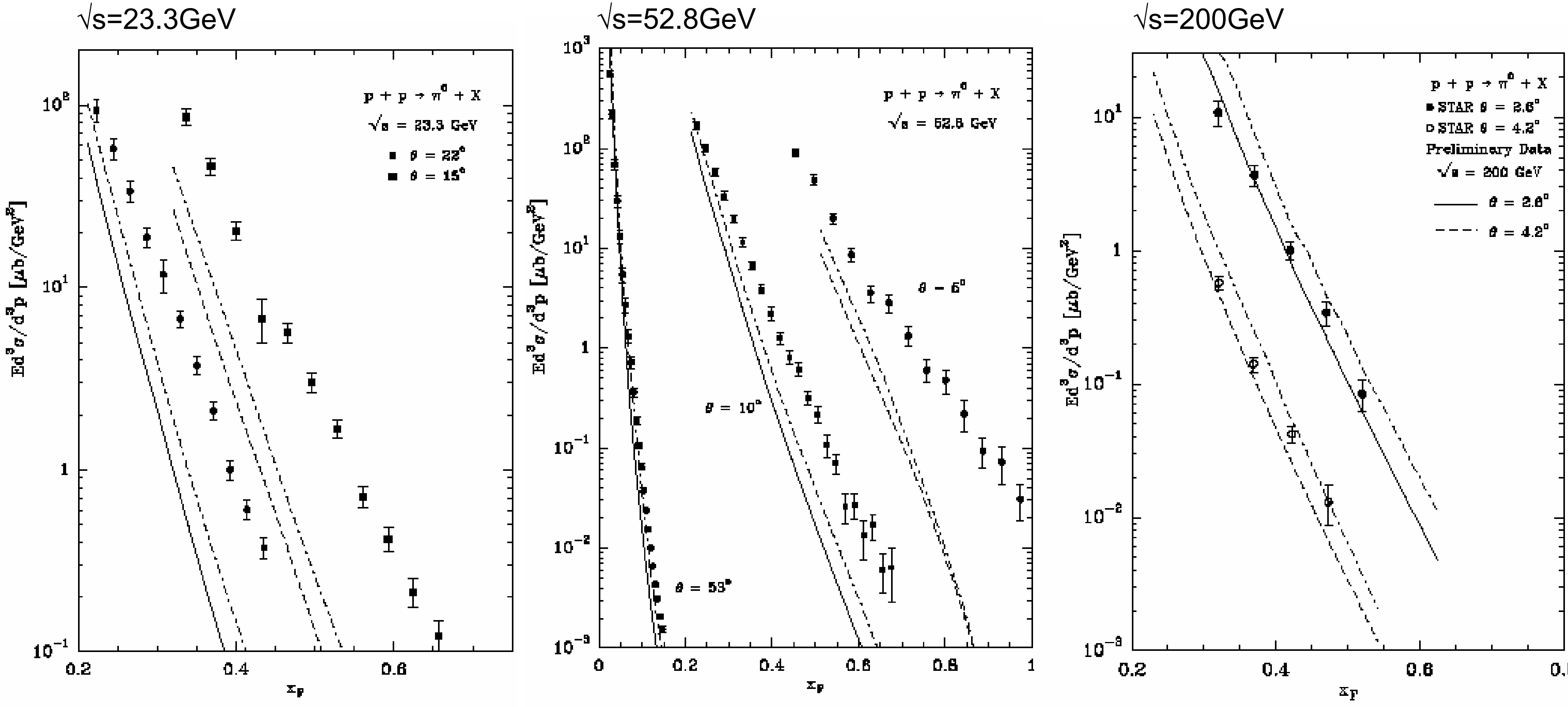
Forward π^0 production cross-section in comparison to NLO calculations



- Measured forward π^0 production cross-section in comparison to NLO pQCD calculations
- NLO pQCD calculations:
  - CTEQ6M parton distribution function
  - Equal renormalization and factorization scale set to p_T
  - Two sets of fragmentation functions:
    - ⇨ Kniehl-Kramer-Pötter (KKP)
    - ⇨ Kretzer
- Measured results fall in-between two NLO pQCD which reflect uncertainties in the underlying fragmentation functions
- Data compares favorably to NLO pQCD at $\sqrt{s}$ = 200GeV in contrast to fixed-target or ISR energies

First results (STAR)

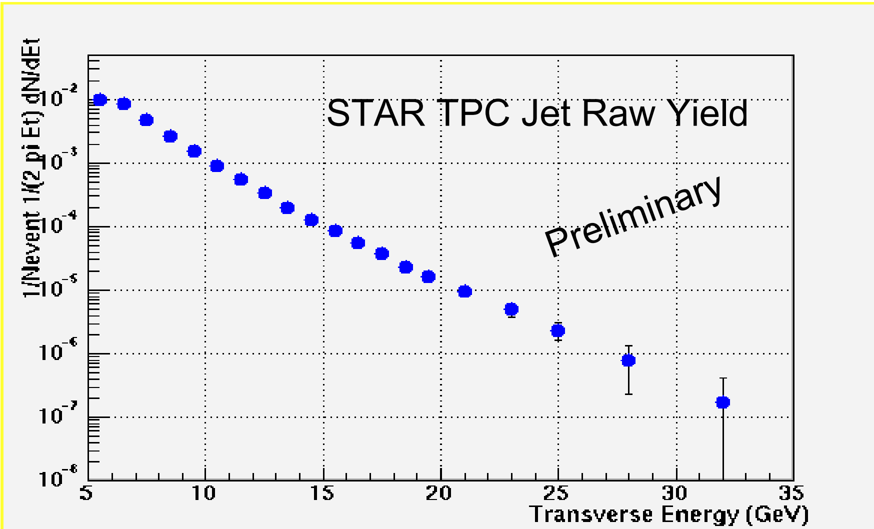
- RHIC forward π^0 production cross-section in comparison to lower energy data

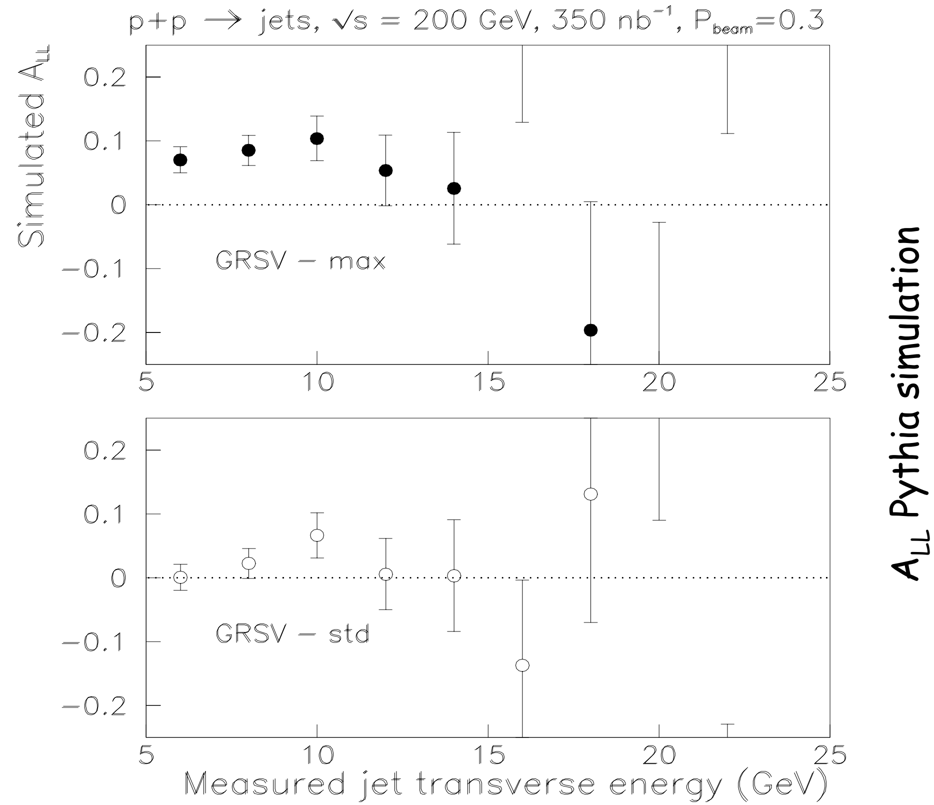


- Bourelly and Soffer (hep-ph/0311110): Comparison of forward π^0 production to pQCD NLO calculations
- Comparison illustrates that agreement of measured cross-sections to pQCD NLO calculations for forward π^0 production improves with increasing center-of-mass energy, i.e. from fixed-target to RHI

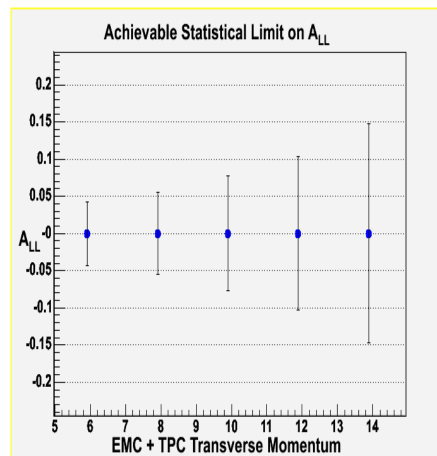
First results (STAR)

- ## Inclusive jet production (FY03)





- First longitudinal data sample will allow to have a first look at A_{LL} for inclusive jet production
- Condition:
  - Average polarization: 0.25
  - Integrated luminosity: 400nb-1
  - Cone-jet algorithm
  - Trigger:
    - ⇨ High-tower trigger (700k recon. jets): Single tower energy threshold above ~2.4GeV
    - ⇨ Jet patch trigger (250k recon. jets): Jet patch ($\Delta\eta$ X $\Delta\Phi$ = 1 X 1) energy threshold E_T>5GeV
- Expected stat. precision on A_{LL} (EMC+TPC)



More data needed!

The PHENIX detector

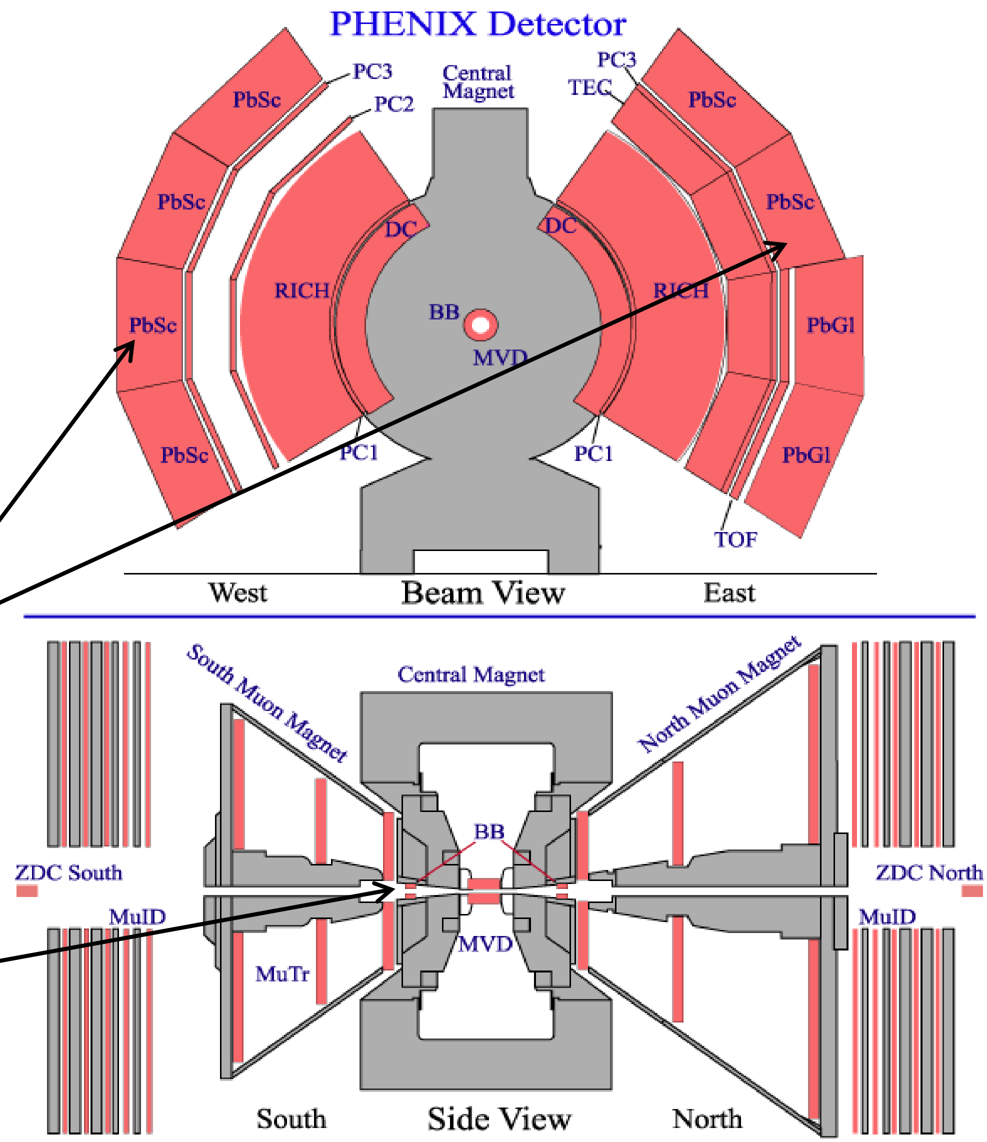
- **Overview**

- Main concept of PHENIX:
  - High rate and granularity
  - Good mass resolution and particle ID

- Commissioning of spin scaler system and relative luminosity monitor for first polarized pp run

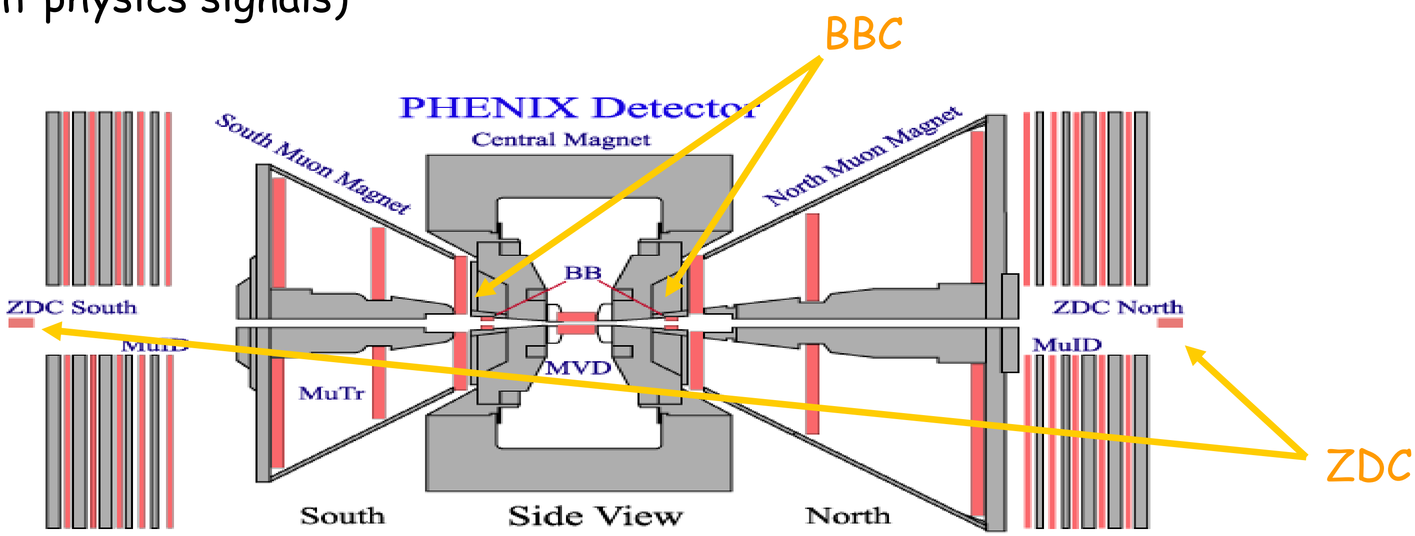
- Reconstruction of π^0 mesons and high p_T photon trigger:
  - ➢ EMCal: $|\eta|<0.38$, $\Delta\varphi=\pi$, granularity $\Delta\eta\times\Delta\varphi = 0.01\times0.01$

- Minimum Bias trigger and Relative Luminosity:
  - ➢ Beam-Beam Counter (BBC): $3.0<|\eta|<3.9$, $\Delta\varphi=2\pi$



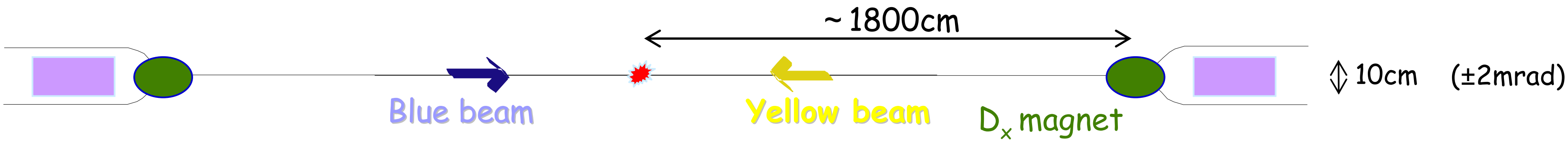
The PHENIX detector

- **Relative luminosity measurement: PHENIX BBC and ZDC**
  - Both, Beam-Beam Counter (BBC) and Zero-Degree calorimeters (ZDC) are used in the relative luminosity measurement (Important cross-check!)
  - Achieved relative luminosity precision $\delta R = 2.5 \cdot 10^{-4}$
    - Pessimistic estimation limited by ZDC statistics (30 times less than BBC statistics used in Rel. Lum. measurements)
  - A_{LL} of BBC relative to ZDC consistent with 0 (<0.2%)
    - Strong indication that both A_{LL}s are zero (Very different kinematical regions, different physics signals)



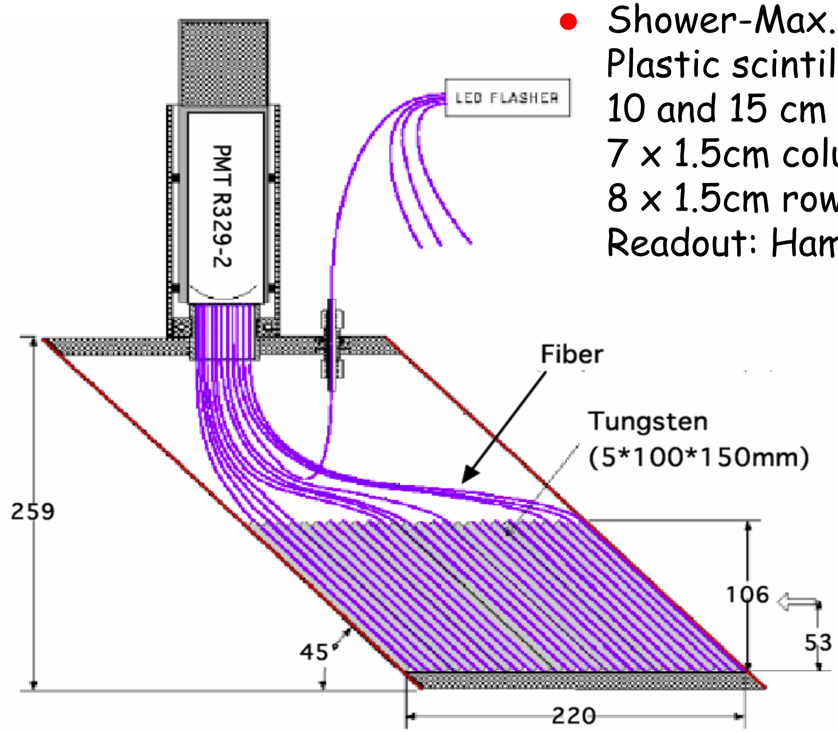
The PHENIX detector

- PHENIX local polarimeter upgrade: ZDC-SMD



- Zero Degree Calorimeter (ZDC): Tungsten-fiber sandwich calorimeter

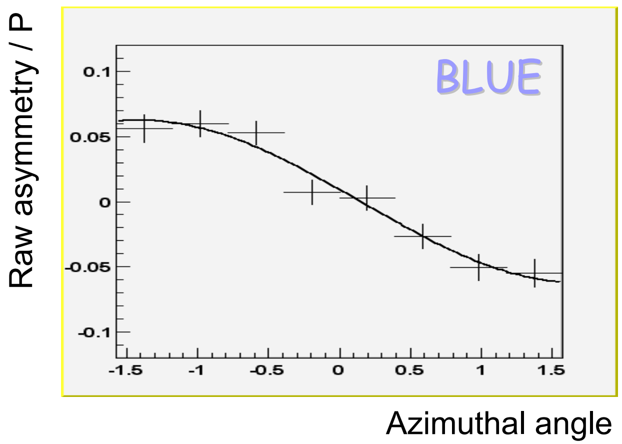
- Shower-Max. Detector (SMD):
  Plastic scintillator strips (0.5cm x 3)
  10 and 15 cm long
  7 x 1.5cm columns
  8 x 1.5cm rows
  Readout: Hamamatsu MAPMT

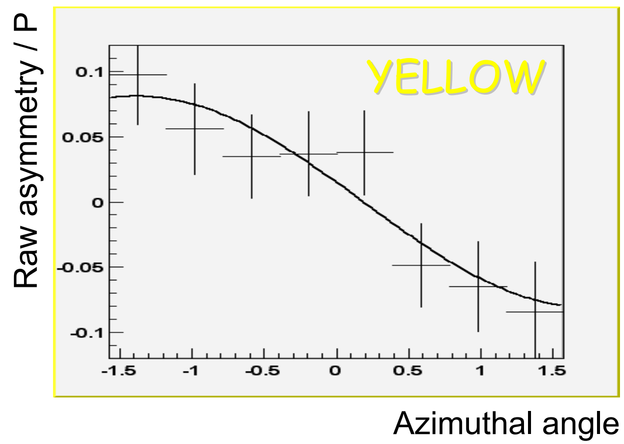


First results (PHENIX)

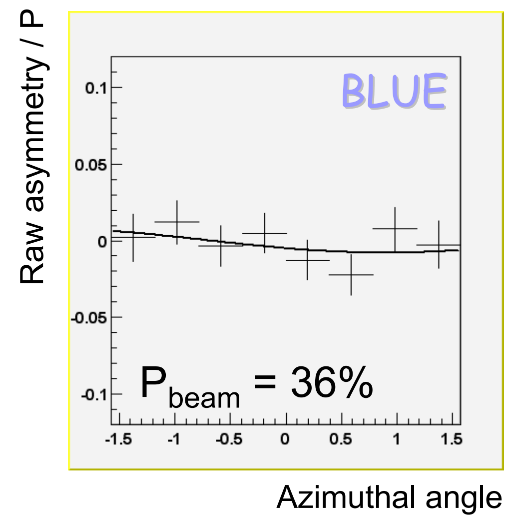
- ZDC asymmetries: Used for PHENIX spin rotator tuning during FY03 run

  - Transverse polarization (Maximum at ±π/2):

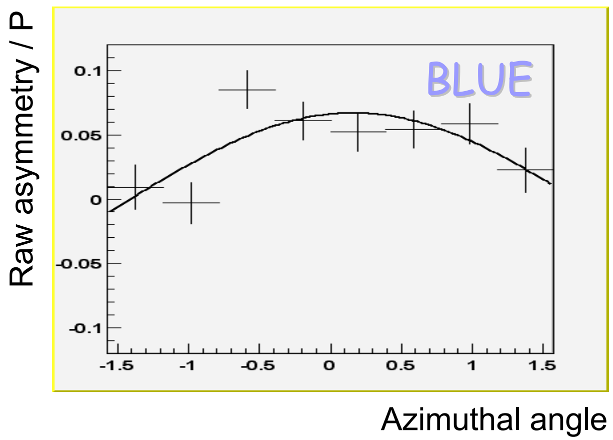


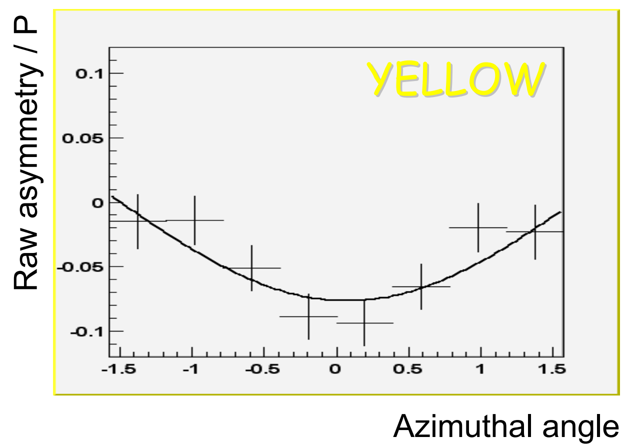


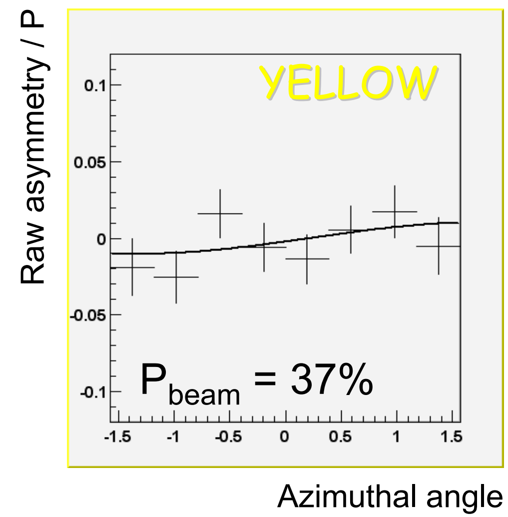
  - Longitudinal polarization (ZERO):



  - Transverse-radial polarization (Maximum at 0): Wrong rotator wiring!







First results (PHENIX)

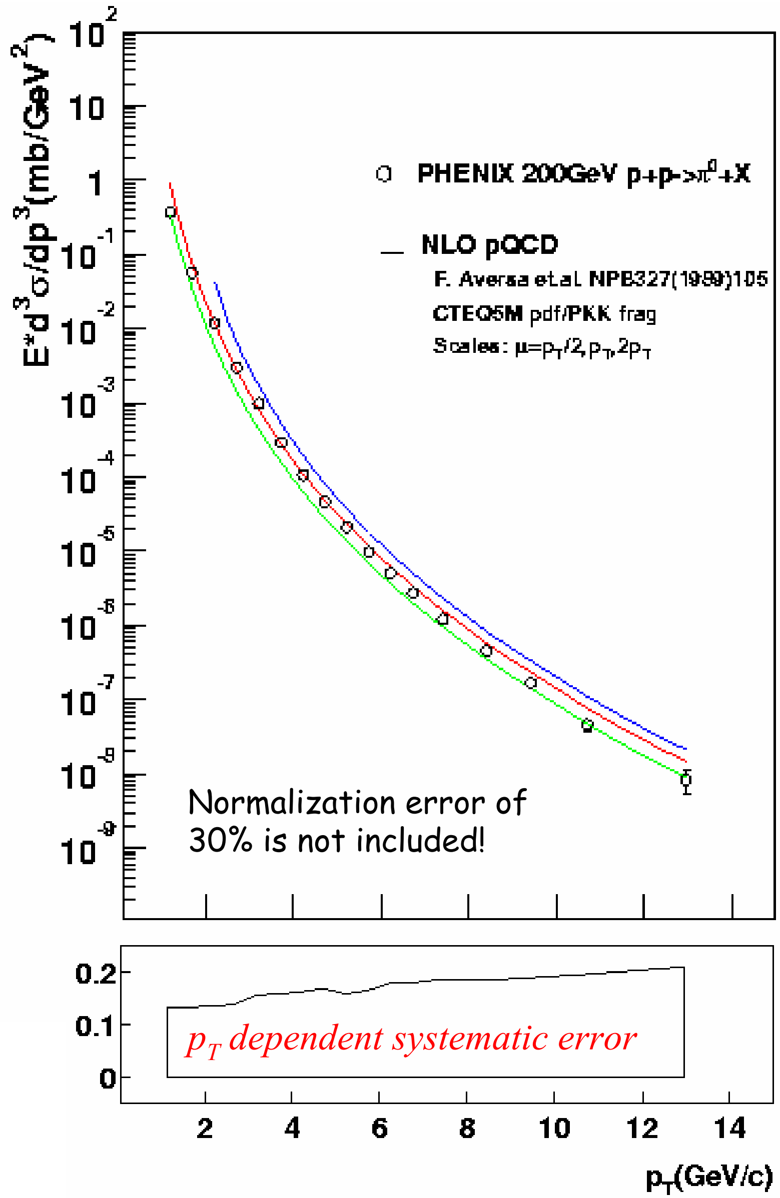
- PHENIX π^0 production cross section

  - Data covers over 8 orders of magnitude
    - p_T = 1 – 13 GeV/c
    - based on combining minimum bias trigger and EMCal trigger data

  - NLO pQCD calculation is consistent with data
    - CTEQ5M PDF + PKK FF
    - with a scale variation: $\mu = p_T/2$ and $2p_T$

⇨ Confidence in understanding subprocesses

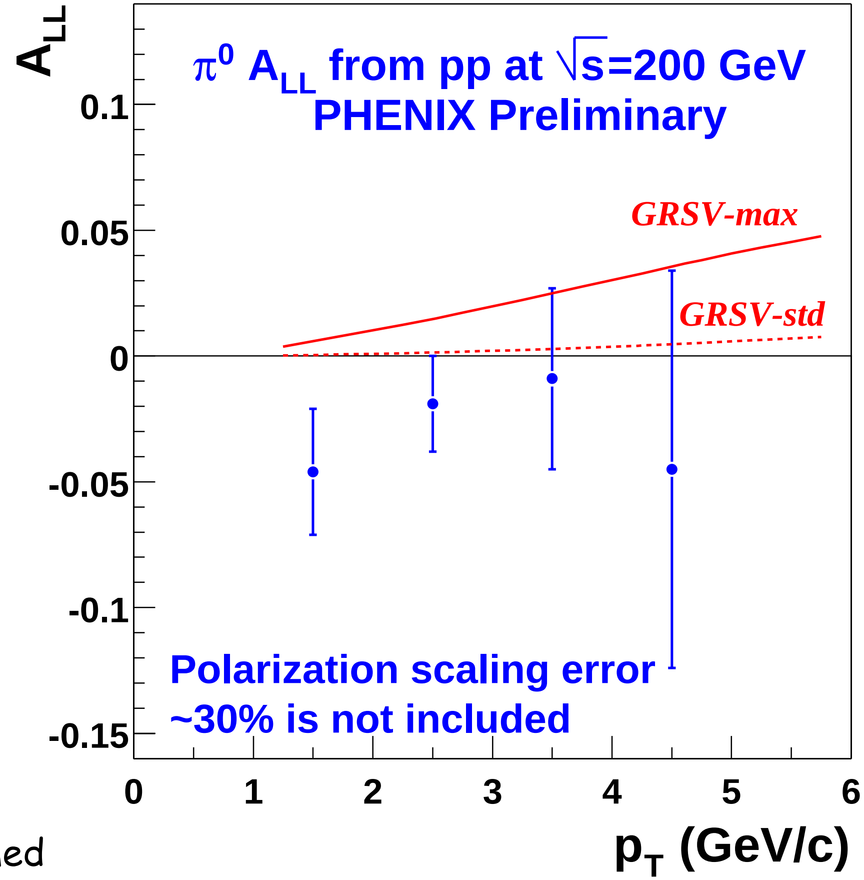
⇨ Solid basis for future polarized pp asymmetry measurements



First results (PHENIX)

- First measurement of A_{LL} at RHIC for inclusive π^0 production

p_T GeV/c	$A_{LL}^{\pi 0+bck}$ (r_{bck})	A_{LL}^{bck}	$A_{LL}^{\pi 0}$ (Background subtracted)
1-2	-0.028±0.012 (45%)	-0.006±0.014	-0.046±0.025
2-3	-0.022±0.015 (17%)	-0.035±0.027	-0.019±0.019
3-4	-0.002±0.033 (7%)	0.094±0.092	-0.009±0.036
4-5	-0.023±0.074 (5%)	0.38±0.24	-0.045±0.079

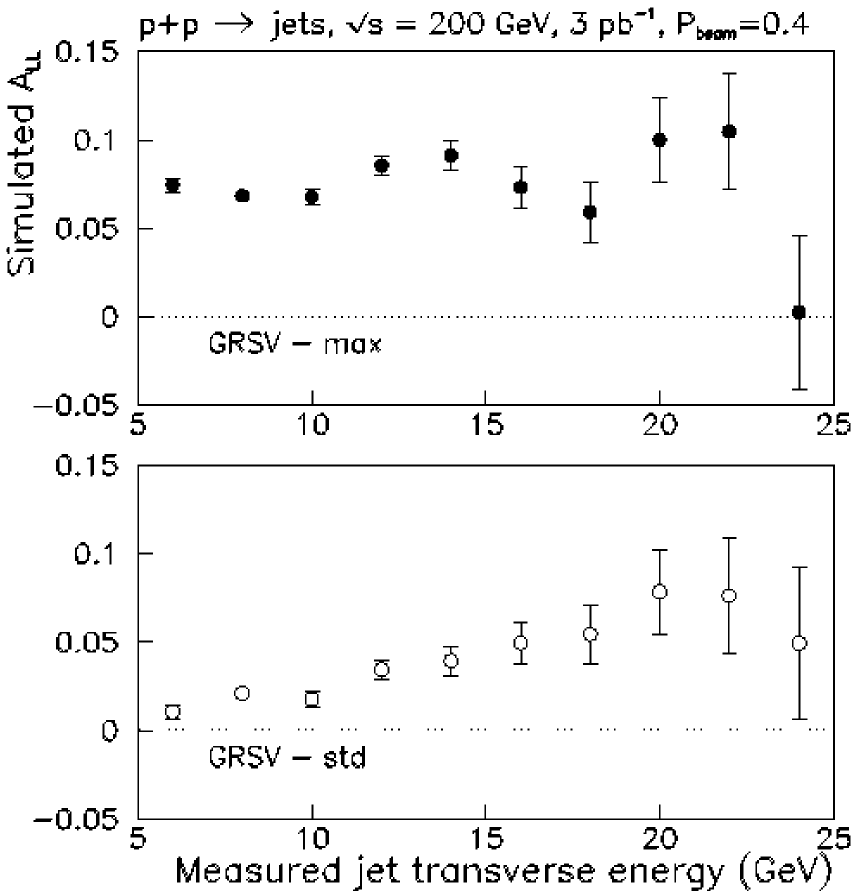


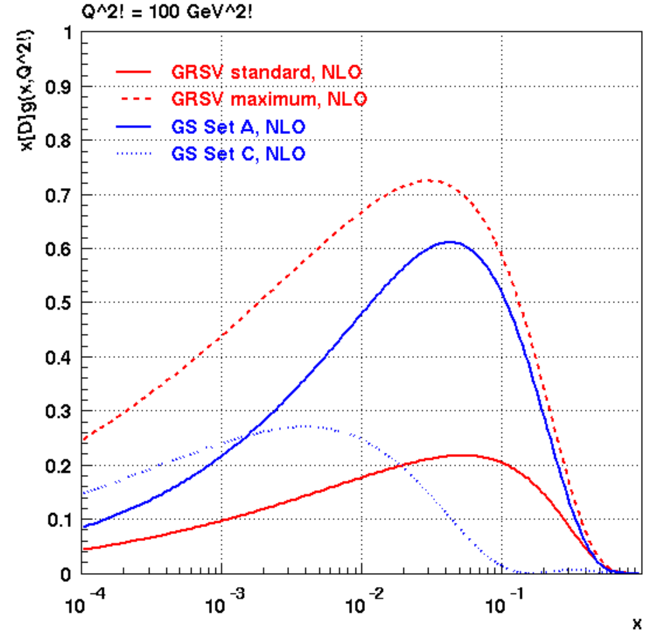
- Polarization scaling error δP ~30% is not included:
  - Enters A_{LL} in quadrature
  - Analyzing power A_N(100 GeV) ~ A_N(22GeV) is assumed
  - δP ~ 30%: combined stat. and sys. error for A_N(22GeV) (AGS E950)
- Relative luminosity contribution to π^0 A_{LL} error is <0.2%
- p_T smearing correction is not included

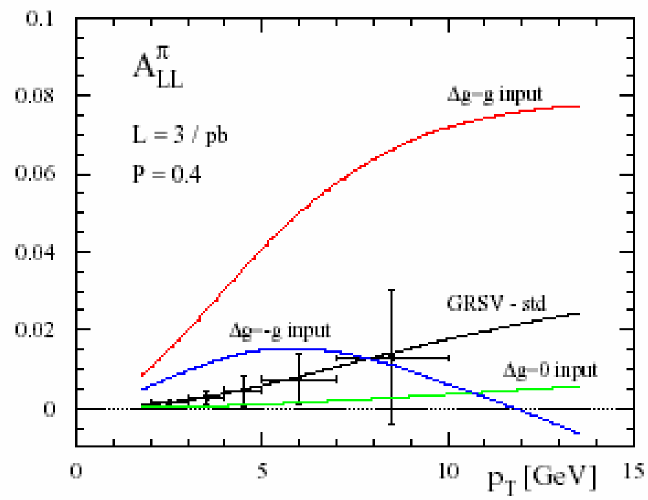
More data needed!

Future prospects

- Prospects on constraining ΔG in RUN4





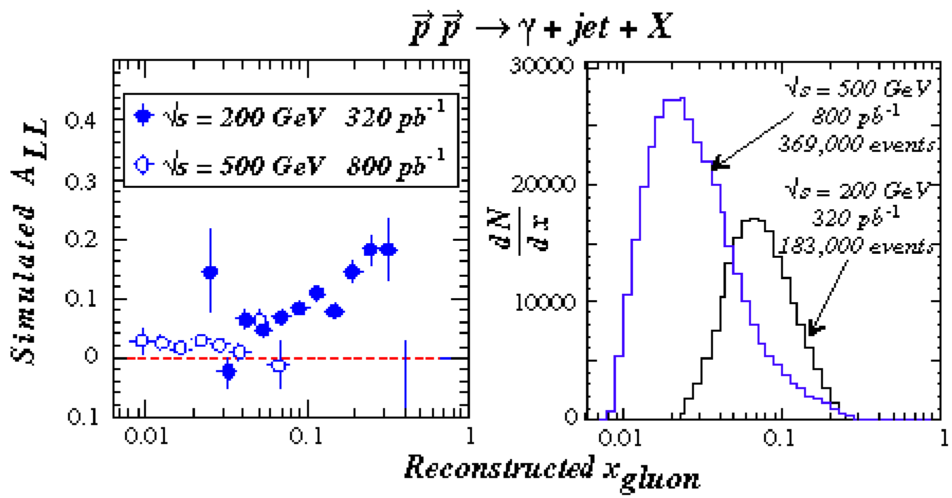


Mention here PHENIX pi0!

Future prospects

Quark-Gluon Compton scattering: Prospects at STAR

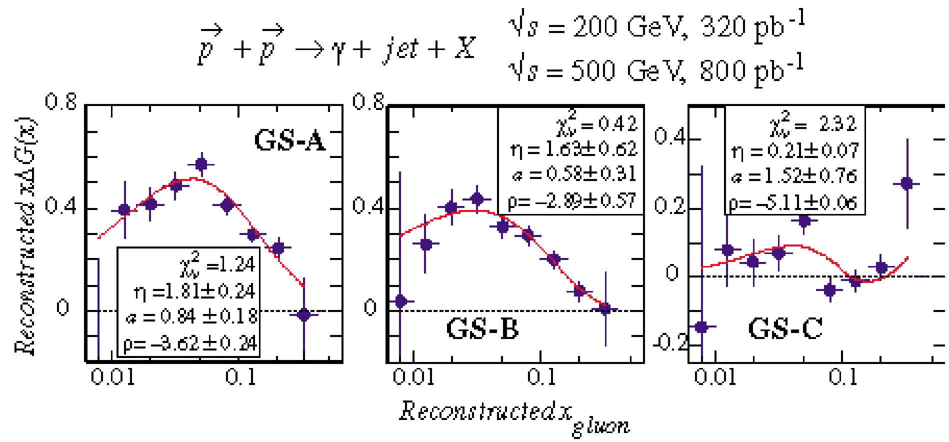
- Simulated A_{LL} at two different RHIC center-of-mass energies:



⇨ Multi year program at RHIC which requires:

1. High luminosity
2. High polarization
3. √s = 200 / 500GeV

$$A_{LL} \cong \frac{\Delta G(x_g)}{G(x_g)} \cdot A_1^p(x_q) \cdot \hat{a}_{LL}^{(g+q\rightarrow\gamma+q)}(\cos\vartheta^*)$$



⇨ Combined data sample at 200 GeV and 500 GeV is essential to minimize extrapolation errors in determining ΔG:

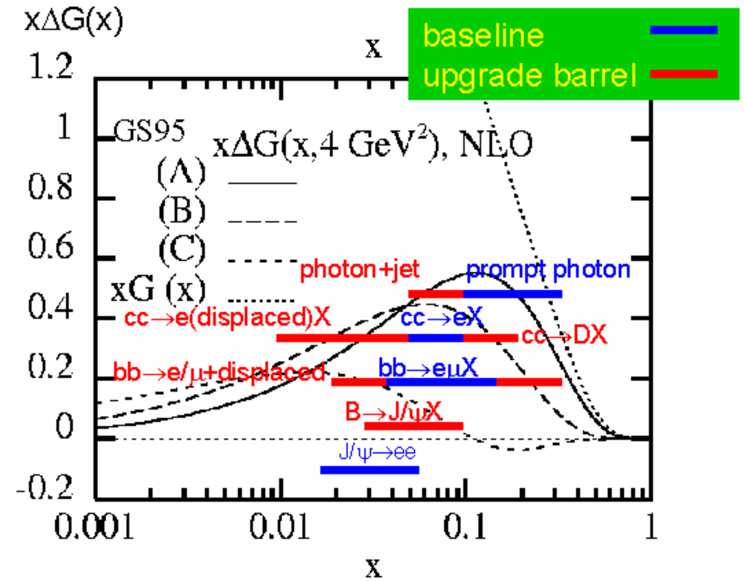
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)\,dx$$

Accuracy: 0.5

⇨ Ultimately: Global analysis of various ΔG!

Heavy Flavor production: PHENIX VTX upgrade

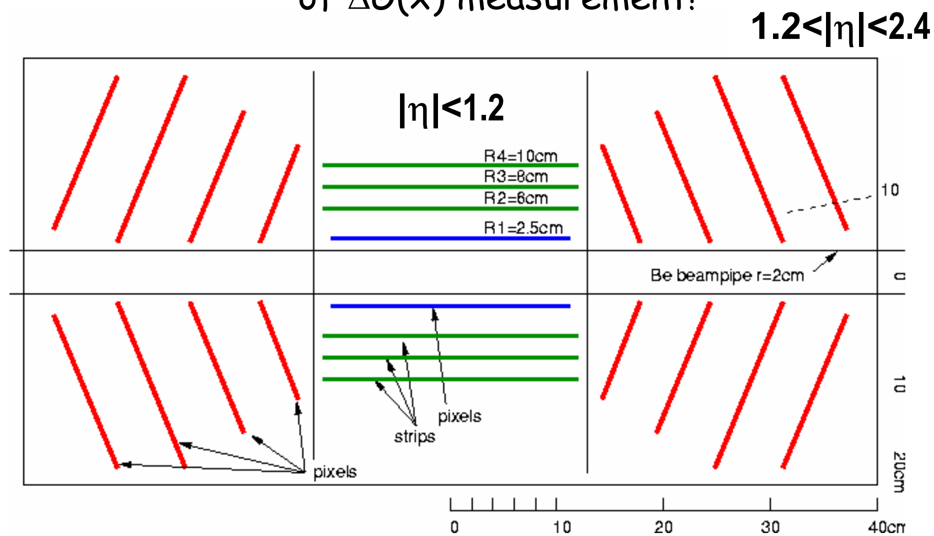
- Measurement of Gluon polarization by Heavy flavor production
  - c, b → e, μ + displaced vertex
  - B → displaced J/ψ
  - D → Kπ at high pt
- VTX measurement of displaced vertex
  - Improved S/B → higher sensitivity to ΔG(x)
  - Broader *x* coverage



⇨ VTX increases the x coverage of ΔG(x) measurement!

Pixel barrels (50 mm x 425 mm)
Strip barrels (80 mm x 3 cm)
Endcap (extension) (50 mm x 2 mm)

1 - 2% X_0 per layer
barrel resolution < 50 mm
endcap resolution < 150 mm



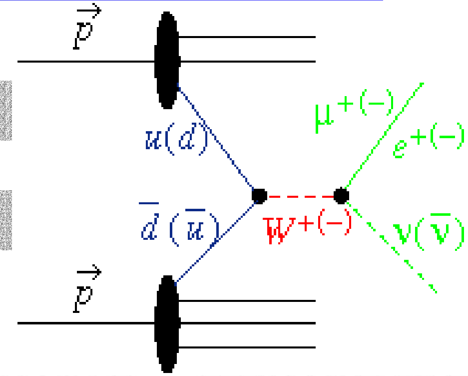
Future prospects (STAR)

W production: Flavor dependence

- $W^{\pm}$ production in pp collisions probes flavor structure of QCD sea analogous to deep-inelastic scattering
- Polarized proton beams allow the measurement of (the expected large) parity violation in $W^{\pm}$ production
- Forward e (μ) detection (STAR forward tracking upgrade needed!) (⇨Asymmetric partonic collisions!) gives direct access to probe the underlying quark (anti-quark) polarization which is dominated at RHIC by u/d quarks

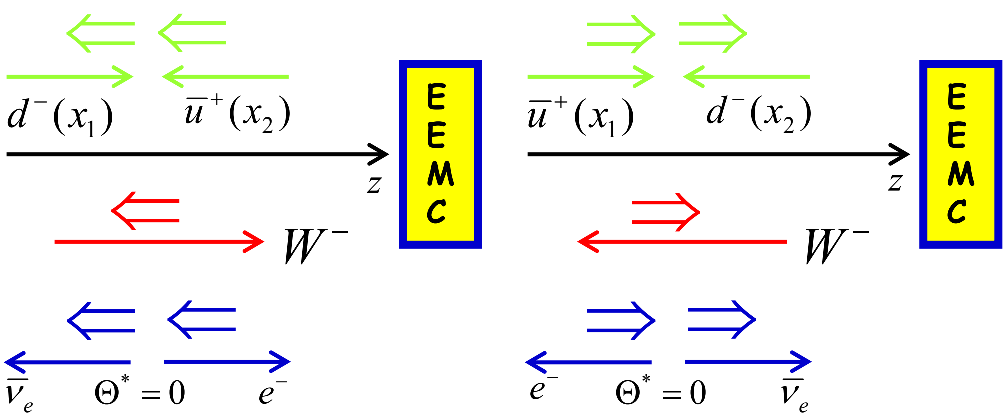
$$W^{-} \rightarrow d + \bar{u}$$

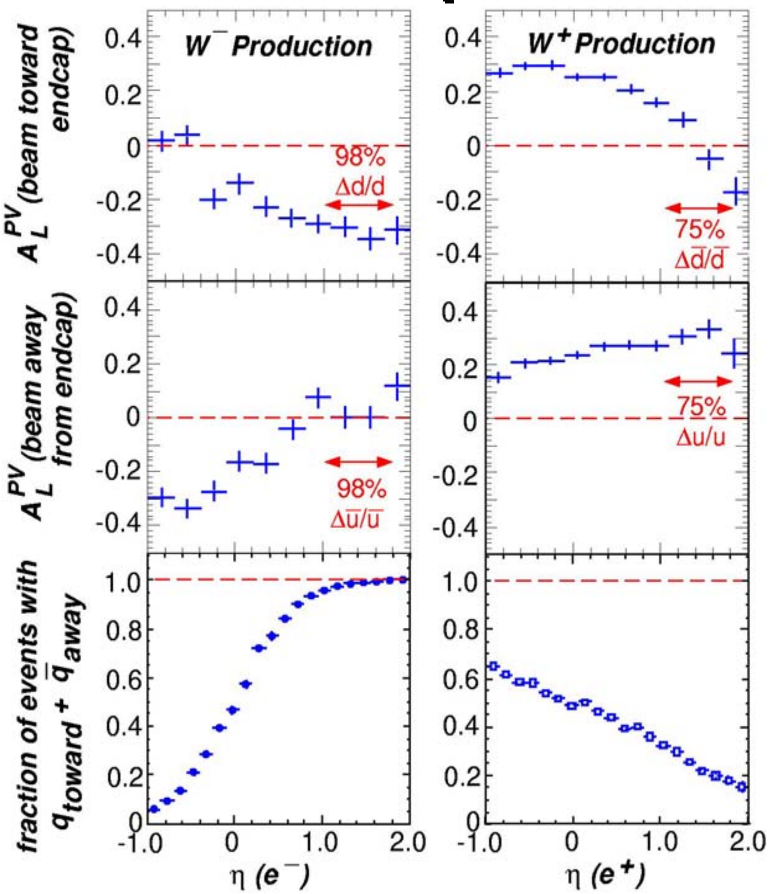
$$W^{+} \rightarrow u + \bar{d}$$



$$A_L^{e-}(\vec{p}p) \rightarrow \Delta d / d$$
$$A_L^{e-}(p\vec{p}) \rightarrow \Delta\bar{u} / \bar{u}$$

$$A_L^{e+}(\vec{p}p) \rightarrow \Delta u / u$$
$$A_L^{e+}(p\vec{p}) \rightarrow \Delta\bar{d} / \bar{d}$$





Summary and Outlook

- RHIC Spin program at BNL
  - First successful polarized proton collisions ever at RHIC (transverse and longitudinal)
  - Successful upgrade and commissioning of various new STAR /PHENIX components for the first polarized proton run at RHIC
  - First measurement of AN (STAR) and AN (PHENIX)
  - First measurement of ALL (PHENIX) and STAR (JETS)
  - Unique opportunity to explore the spin structure and dynamics of the proton in a new unexplored regime at RHIC over the next years.
    - Gluon polarization
      - Short-term: Pi0 and Jets
      - Long-term: Prompt photons and heavy quark production
    - Flavor decomposition (W production)
    - Transverse spin dynamics (AN) and transversity
  - This requires various accelerator, polarimeter and detector components to be completed and upgraded! (High polarization and luminosity ⇨ Continuous pp running and development crucial)!